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Alameda County Flood Control and Water
Conservation District, Hayward, CA

Prepared for

Association of Bay Area Governments
Berkeley, CA

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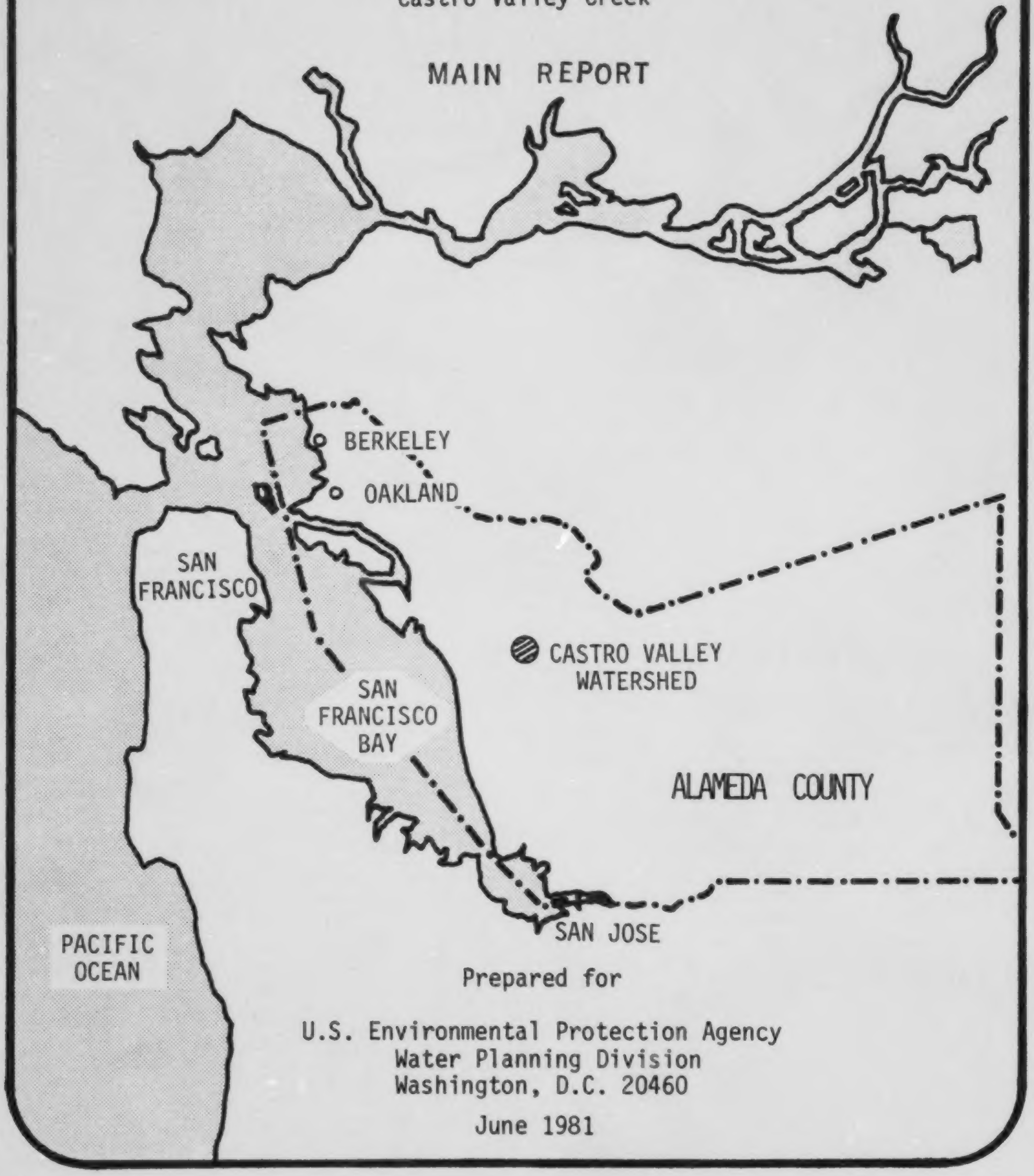
A Demonstration of Non-Point Source Pollution Management on Castro Valley Creek

MAIN REPORT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This report presents the results and conclusions from an EPA-sponsored nonpoint source pollution management project on Castro Valley Creek in Castro Valley, CA, designed to correlate street cleaning and urban runoff water quality. The study area was a suburban 1,542-acre watershed that is considered typical of many residential basins in the San Francisco Bay region. To demonstrate the relationship between street cleaning and runoff, the project was designed to measure the following: (1) street cleaning effectiveness (2) street surface pollutant loadings and (3) runoff water quality. Data were analyzed to correlate street surface pollutant loadings before rain events with changes in runoff water pollution mass yields. This volume contains the main report in full.

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SAN FRANCISCO BAY AREA
NATIONAL URBAN RUNOFF PROJECT

A Demonstration of Non-Point Source Pollution Management on Castro Valley Creek

MAIN REPORT

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DISCLAIMER

This report has been reviewed by the Water Planning Division, U.S. Environmental Protection Agency, and the Alameda County Flood Control and Water Conservation District and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

This report presents the results and conclusions from the EPA-sponsored non-point source pollution management project on Castro Valley Creek in Castro Valley, CA. Non-point pollution in some areas represents a major obstacle to achievement of the goal of the 1972 Federal Water Pollution Control Act Amendments. This was the first prototype project to be part of the Nationwide Urban Runoff Program (NURP) and was designed to correlate street cleaning and urban runoff water quality.

The study area was a suburban 1,542-acre watershed that is considered typical of many residential basins in the San Francisco Bay region. To demonstrate the relationship between street cleaning and runoff, the project was designed to measure the following: (1) street cleaning effectiveness (2) street surface pollutant loadings and (3) runoff water quality. Data were analyzed to correlate street surface pollutant loadings before rain events with changes in runoff water pollutant mass yields.

The project also investigated two other related subjects: One was a comparison of the performance of regenerative air (RA) and mechanical street cleaning equipment. It was determined that the RA equipment was more effective than the mechanical equipment only under very clean street surface conditions. The other subject involved assessing the magnitude and severity of asbestos pollution in urban areas and waters. It was found that there are substantial quantities of asbestos on street surfaces and in urban runoff but the current limited water quality criteria does not provide a basis for determining if there is a problem. Automobiles appear to be an important source of street surface asbestos.

As a result of two years of effort, this project demonstrated that street cleaning can effect a substantial reduction in the amount of lead and total solids, as measured in the runoff water. A maximum of thirty-five percent (35%) of lead and twenty percent (20%) of total solids can be prevented from entering the runoff by very frequent street cleaning (greater than 3 passes per week). Information on the effectiveness of less frequent sweeping was also developed. The results of this project in conjunction with other NURP street cleaning projects will help identify the role of street cleaning in meeting the goals of the 1972 Federal Water Pollution Control Act Amendments.

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SECTION 1

EXECUTIVE SUMMARY

Introduction

- This document is the final report of a study conducted to develop information on the control of urban runoff and the potential impacts on water quality.
- The study focused on a small urban feeder creek in the San Francisco Bay Area: Castro Valley Creek.
- The work was performed by Alameda County Flood Control and Water Conservation District (ACFC&WCD) and the U.S. Geological Survey (USGS), with technical guidance by Woodward-Clyde Consultants.
- Funding support came from Alameda County Flood Control and Water Conservation District (ACFC&WCD), U.S. Environmental Protection Agency (EPA) and U.S. Geological Survey (USGS).
- Administrative support was provided by the Association of Bay Area Governments (ABAG), by coordinating grant arrangements.
- Technical review and comment were provided by representatives from the U.S. Army Corps of Engineers (CORPS), the U.S. Geological Survey and the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB).
- The study focused on developing basic technical information which local decision-makers need to formulate strategies for urban runoff control.
- The study is an important component of EPA's Nationwide Urban Runoff Program (NURP) to help identify the role of street cleaning as a measure to control non-point pollution from urban streets.

The report consists of 8 sections and 9 supportive appendices arranged as follows:

The Executive Summary presents an overview of the project. It is designed to be a complete (yet abbreviated) report with information especially pertinent to local public works officials. The summary is arranged as follows:

The Background presents technical perspective on urban runoff with a discussion of contributions from pollutant source areas which is germain to understanding the approach and findings reported herein. It also presents the study's objectives and methodology. The Conclusions portion presents the principal questions which the project sought to answer and summarizes the major findings in the form of answers to the questions.

The remaining sections discuss the interpretation of the data collected on the receiving water, the street cleaning and a strategy for control of urban runoff. The appendices basically present the actual data collected.

Background

In water pollution terminology, sources of pollutants are considered either point sources or non-point sources. Point sources are those that discharge pollutants at a single, easily identifiable location; e.g., municipal and industrial treatment plant discharges. Non-point sources are diffused sources and are those that discharge at many locations; e.g., storm water runoff.

Most of the Federal, State and local water quality control efforts to date have been directed at point sources. Lack of past attention to non-point sources leaves them as a major obstacle for obtaining water quality goals. Governments at all levels need to determine whether the control of non-point sources, such as urban runoff from street surfaces, will provide greater receiving water benefits at less cost than additional control of point sources; e.g., municipal sewage treatment.

Past research has revealed the substantial water pollution potential of street surface contaminants (Sartor and Boyd, 1972). Although it is quite clear that street dirt pollutants have a significant effect on the quality of receiving waters, questions remain about the cost and effectiveness of street cleaning. Information on the cost and effectiveness is necessary in order to help demonstrate the potential role of street cleaning for the management of water quality in order to help meet the swimmable, fishable waters goal of the Federal Water Pollution Control Act Amendments, Public Law (PL) 92-500.

Contributions from Pollutant Source Areas

Many sources in the urban area are recognized as being contributors of urban runoff pollutants. Street surfaces are urban source areas that are quite important because they contribute significant quantities of several heavy metals and asbestos, whereas oxygen demanding materials and nutrients are believed to originate mostly from landscaped areas and areas of vacant land. Vacant and landscaped areas tend to be among the most permeable surfaces in an urban area, tend to be located farthest from the storm sewerage system and also contribute little flow during an urban runoff event to the receiving water. Therefore, very little potential pollutant yields reach the storm sewer outfalls into Castro Valley Creek. Characteristics of the Castro Valley study area are presented in Appendix A.

Roof tops, are also located at relatively long distances from the storm sewers. Because roof tops are not directly connected to the storm sewerage system in Castro Valley their pollutant yield to the receiving waters is very small. Street surfaces on the other hand are located close to the storm drainage system and are almost totally impermeable. Most of the runoff that originates from street surfaces is expected to reach the receiving water.

The amount of pollutants in urban runoff depends (in part) upon the size and frequency of rain events. Stated simply:

- Larger events are capable of removing and transporting greater amounts of pollutants from their source areas to the receiving waters.
- The less frequent the events the more time is available for pollutants to accumulate on the source areas.

It is estimated that, if all of the total particulate pollutants deposited in the study area portion of the Castro Valley Creek watershed were totaled, only about 30 percent would reach Castro Valley Creek via urban runoff. Also, it is estimated that only 10 percent of the nutrients and oxygen demanding materials deposited in the contributing area would reach the creek. On the other hand, most of the heavy metals in the area would be expected to reach the creek. These differences are related to the fact that the remaining pollutants (i.e., those that are washed off the source areas but do not reach the outfall) tend to be trapped or otherwise accumulate in other areas in the urban environment. The most significant areas of accumulation are the soils, vegetation, and possibly groundwater.

Objectives

The study described herein was directed towards developing information on three subjects which were of particular concern to local decision makers and the nationwide urban runoff program. The objectives were to:

1. Demonstrate the effectiveness of street cleaning in improving water quality.
2. Provide information to local Public Works Agencies on how to incorporate water quality as a factor into their street cleaning programs.
3. Investigate the quantities of asbestos on urban streets and in urban runoff.

Again, the primary purpose of the project was to demonstrate whether removing the pollution load from street surfaces by street cleaning has an affect on urban runoff quality. The project collected data to compare the monitored mass pollutant flows of the storms with the total pollutant removal of street cleaning programs. A valid data set for this analysis consisted of a data point for a monitored runoff event that occurred between, before and after street surface monitoring data points. During the two years of this study, 22 valid data sets were collected.

Methodology

Project field activities began in October, 1978, and ended in April, 1980. In order to demonstrate the relationship between street cleaning and runoff water quality, the project measured:

(1) street cleaning effectiveness, to identify the quantity of pollutants removed and the initial and residual loadings before and after cleaning for a variety of street cleaning programs. The street surface particulate sample was obtained by vacuuming portions of the street surfaces immediately before and after the area was cleaned. The two loadings were then compared to obtain measures of street cleaning effectiveness. These samples were then divided into eight discrete particle sizes, weighed, then composited over selected time periods by particle size and test area for chemical analyses. The resultant street surface pollutant loadings were then available for comparison;

(2) street surface pollutant accumulation rates to identify the loading on the street at any time;

(3) precipitation, to know the quantity of rainfall; and

(4) receiving and runoff water quantity and quality, to identify the quantity of pollutants washed off the watershed for various types of rainstorms. Two monitoring stations were located on Castro Valley Creek. The upper station (Seaview) measured the runoff from the rural area, and the lower station (Knox) measured the runoff from both the urban area and the rural area. The contribution from only the urban test area was determined by subtracting the contribution of the rural station from that of the lower station.

Curve fitting analyses was used to correlate street surface pollutant loadings before rain events with changes in runoff water mass yields.

Example calculations for determining (1) street surface loadings in pounds per curb mile, (2) median particle size of the street surface particulates and (3) mass emissions from storms, are provided in Appendix B.

Conclusions

Research funded by the Environmental Protection Agency (EPA) and the Alameda County Flood Control and Water Conservation District (ACFC&WCD) was conducted to demonstrate whether street cleaning activities can significantly affect urban runoff water pollution.

During the development of the study, the investigators formulated a series of specific questions which related directly to the previously stated objectives. The many study tasks were designed and conducted to develop answers to these questions. These questions and the conclusions of the study are listed below:

1. Question

- To what extent is receiving water quality a function of street cleanliness?
- Is there a problem in the receiving water?
- How clean does the receiving water need to be?
- What standards apply and how do they apply to wet weather beneficial uses?

Conclusion

In order for Castro Valley Creek to meet recommended water quality criteria, significant reductions in the amounts of the toxic metals lead, cadmium, copper and zinc - would be necessary during wet weather conditions.

The standard of most relevance is the aquatic life criteria (established by EPA and published in the Federal Register November 28, 1980). Beneficial uses of the creek established by the State include water contact and non-contact recreation as well as aquatic habitat. Castro Valley Creek does have a water quality problem because it conveys toxic pollutants in concentrations that exceed established standards and in large quantities into San Francisco Bay. It may be desirable to control these constituents to upgrade the water quality conditions of the creek and the more important receiving water, San Francisco Bay.

2. Question

Which pollutants can be controlled by street cleaning and to what extent?

Conclusion

A maximum of thirty-five percent (35%) of lead and twenty percent (20%) of total solids could be prevented from entering receiving waters by conducting frequent street cleaning activities. Other constituents, e.g., arsenic, chemical oxygen demand, and copper could be reduced by less than ten percent.

In a typical watershed, most of the lead available for washoff by rain events comes from street surfaces. This lead originates through the combustion of leaded gasoline in motor vehicles. Lead shows the greatest potential for control by street cleaning because the largest and almost only source of lead is from the combustion of leaded gasoline. If lead is ever removed from gasoline then this source would be nearly eliminated but lead may be used as a gasoline additive for a long time. Nutrients have less potential for control by street cleaning because there is a much larger quantity of nutrients on non-street areas (e.g., rooftops, lawns) in a watershed.

3. Question

How do alternative equipment types differ in performance?

Conclusions

Regenerative air (RA) street cleaning equipment was demonstrated to be more effective than mechanical brush type equipment, but only in areas that have very clean street surfaces.

Removals obtained by the RA equipment at the lower initial particulate loading values were substantially greater than for the standard mechanical brush street cleaner. However, under more typical (dirtier) loading conditions, the difference between these two types of equipment diminishes to insignificant levels.

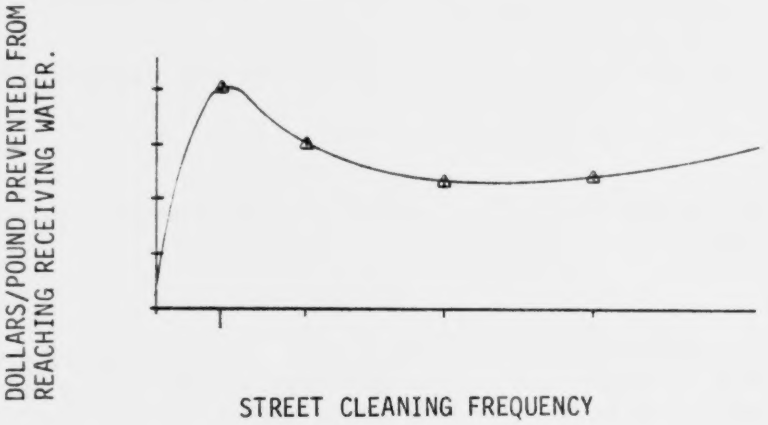
4. Question

What are the cost effectiveness relationships between street cleaning programs and receiving water quality?

Conclusion

A frequent street cleaning program may have smaller unit costs to prevent pollutants from entering receiving waters than infrequent cleaning.

Annual street cleaning costs tend to increase linearly as a function of the cleaning frequency. Further, the cost to remove a unit of pollutant from the street increases steeply with increased street cleaning. However, the cost to prevent a unit a pollutant from entering the receiving water by street cleaning does not follow an increasing unit cost pattern as shown below.



Source: Figure 1-5.

When going from a twice per month frequency to a three times per week frequency, the unit removal costs for total solids during the period of study actually decreased. Considering the weather patterns in the Bay Area, the best return for the limited street cleaning money is to clean the streets before the first rain of the year and then three times per week between the other winter storms.

5. Question

What portion of various types of pollutants are readily carried from various surfaces to receiving waters by common storms?

Conclusions

To prevent a given amount of material from entering the receiving water requires the removal from the street of ten to one hundred times that amount of material for selected contaminants, on an annual average.

The constituents, total solids, chemical oxygen demand, total phosphorus, orthophosphate, lead, and zinc all require the removal of about ten units of the material from the street to prevent one unit of material from entering the receiving water. Total Kjeldahl nitrogen and copper require almost one hundred times removal.

This concept of removal ratios is central to the report and is discussed in Chapter 6.

6. Question

How effective are alternative street cleaning schedules in reducing receiving water impacts?

Conclusion

A street cleaning frequency of three passes per week would provide the optimum reduction of street surface contaminants for the Castro Valley watershed. More than three passes per week would result in little additional improvement.

7. Question

What control strategies can be used to account for the fact that large amounts of pollutants tend to accumulate in certain areas?

Conclusion

The most cost effective street cleaning strategy for preventing pollutants from entering receiving waters would be to clean the dirtiest streets more frequently than the clean streets.

It costs almost the same amount to operate street cleaning equipment on a dirty street as on a clean street. However, the same effort and money can remove much more material from dirty streets than from clean streets. To achieve the lowest unit cost removals requires cleaning the dirtiest streets more frequently than the cleaner streets. Normal municipal practice is to have the highest street cleaning frequency devoted to the downtown streets (which tend to be the cleanest). Substantial water quality improvements could be realized with no increase in budgets by changing present street cleaning objectives to consider water quality along with aesthetics.

8. Question

How does the concept of seasonal weather differences affect street cleaning strategies?

CONCLUSION

Because of the Bay Area's climatic patterns (wet winters, dry summers), a relatively intense street cleaning program should be maintained before the first storm of the year and during the wet season.

The frequency of street cleaning during the different seasons is important in the various climate categories. In California, large rains can occur at the beginning of the rain season. Other times, these large rains occur later in the season with less time between storms to allow for accumulation of street surface contaminants. Large storms may contribute substantial amounts of erosion material to the streets.

9. Question

What is the cost-effectiveness of inlet cleaning compared to other control measures?

Conclusion

Based upon limited sampling, inlet cleaning appears to be a cost-effective non-point source control measure.

Because of the design of drop inlets, they receive large amounts of street dirt and debris and it is relatively easy to remove the accumulated material. Most of the material cleaned from drop inlets is prevented from reaching the receiving water, whereas a relatively smaller fraction of the material removed by street cleaning and erosion control is prevented from reaching the receiving waters. When compared to various urban runoff control measures, inlet cleaning seems to be the least costly. With the usual inlet cleaning frequency of once per year, it can only affect about two percent of the annual yield of most of the constituents. However, if it were increased to three or four times per year, inlet cleaning may prevent up to about ten percent of the contaminants from entering receiving waters. This data is based upon very limited sampling and needs further research.

10. Question

How much asbestos in urban runoff originates from man-made sources?

Conclusion

There is substantial asbestos from man-made sources on street surfaces but the current, limited water quality criteria does not provide a basis for determining if there is a problem. Automobile use appears to be an important source of asbestos associated with street dirt.

Urban Runoff & San Francisco Bay

The San Francisco Bay-Delta Estuary is the single most important water body in the State of California. More than one half of all of California's fishery resources either live in or directly depend on the Bay Delta Estuary for their survival. San Francisco Bay also provides scenic beauty and recreation to over 5 million people who live near its shore (California State Water Resources Control Board, 1980).

San Francisco Bay is the dominant feature and primary receiving water of the Bay-Delta system. Assessment of the water quality impact on San Francisco Bay from stormwater runoff is difficult because of the drainage from its vast tributary area. The Bay-Delta system receives runoff from about 40% of the land area of California, or about 63,000 sq. mi. About 3200 sq. mi. of the region drains directly to San Francisco Bay.

The primary use of many creeks in the Bay area is to convey stormwater runoff into San Francisco Bay. Although runoff contains large amounts of pollutants, its relationship to observed water quality problems in San Francisco Bay remains uncertain. However, Castro Valley Creek's contribution of large quantities of toxic pollutants into San Francisco Bay is seen as a significant water quality problem.

As Table 1-1 shows, the two-year average concentrations of lead, cadmium, copper, and zinc measured in Castro Valley Creek during runoff events exceeded the standards set by the U.S. Environmental Protection Agency. Many receiving water average concentrations exceeded not only the 24-hour average concentration standard, but also the maximum allowable concentration criteria. Aquatic life is an established beneficial use of Castro Valley Creek.

TABLE 1-1. CONCENTRATIONS* OF METALS IN CASTRO VALLEY CREEK STORMWATER COMPARED TO AQUATIC LIFE WATER QUALITY CRITERIA

Constituent	Castro Valley Creek[1] Range	Castro Valley Creek[1] Average	Freshwater Aquatic Life Criteria[2] 24 hr. Average	Freshwater Aquatic Life Criteria[2] Maximum Concentration
Cadmium	1-12	5	.051	6.3
Copper	21-700	94	5.6	43
Lead	97-3300	488	20	400
Zinc	72-2200	325	47	570

*All units in ug/l; i.e., parts per billion (ppb).

1. Based upon measurements from October 1978 to April 1980 at the urban station; i.e., Knox Street Station; USGS No. 11181006.

2. Criteria established by EPA for pollutants designated as toxic under Section 307 (a) (1) of the Clean Water Act. These criteria were published in the Federal Register November 28, 1980. These criteria are different for various hardness conditions. Castro Valley receiving hardness is about 200 mg/l as $CaCO_3$. The criteria shown are for these hardness values.

Castro Valley Creek and many other Bay Area creeks with similar flow volumes can be considered "urban feeder creeks". These may be characterized as having low summer flows, large winter flow variations and also providing some natural habitats. It probably is not economically feasible to improve these creeks to a fishable/swimmable status.

Castro Valley, the study area for this project, is a small watershed considered typical of residential basins in the San Francisco Bay Delta Region (Sylvester, 1978). The U.S. Geological Survey and the Corps of Engineers (initially began monitoring runoff in Castro Valley in 1971) considered Castro Valley a typical residential basin because of the general geology, soils, topography, hydrology, climate, vegetation and human activities in the basin. Assessment of the impact from stormwater runoff on the water quality of Castro Valley Creek shows that the runoff water quality commonly fails to meet beneficial use criteria for several toxic heavy metals.

Although it was beyond the scope of this project to investigate the effects of street cleaning on Bay water quality, the project was based on the assumption that, if street cleaning would improve water quality in Castro Valley Creek, then street cleaning on a larger scale may improve water quality in the Bay.

Problem Definition

As a result of the P.L. 92-500, many regions of the nation undertook areawide planning studies (supported by 208 grants) to identify and define existing water quality problems. In the Bay Area, the problems investigated included fish kills, shellfish contamination, toxic pollutants, eutrophication, dredging and disposal, oil and chemical spills, and freshwater outflow from the Sacramento-San Joaquin Delta.

The following is a brief description of three of these problems and their probable causes in the San Francisco Bay Area:

- Shellfish beds are widespread, well-populated, and represent a presently under-utilized resource in San Francisco Bay. Commercial and recreational shellfish harvesting is prohibited because of contamination by bacteria, viruses and, in some cases, heavy metals. Storm runoff, sewage discharge and waste from boats are sources of contamination (ABAG, 1978).

- Many fish kill incidents can be traced to specific pollution causes, however, the fish kills occur in the Bay for unknown reasons. The State is investigating the causes of death of striped bass and has also initiated a study of the aquatic habitat of the Bay.

- There is evidence that the Bay's aquatic life may be adversely affected by toxic materials; e.g., heavy metals, pesticides and organic compounds which are showing up in analyses of Bay waters. The evidence points to pollutants that occur at low concentrations and whose effects are cumulative and/or long-term (ABAG, 1978).

Comparison of Point and Non-Point Sources

Figure 1-1 shows the expected trend and amounts of selected pollutants delivered to the Bay from different sources between 1975 and 2000. Some conclusions for 1985 that can be made from the figure are:

- Surface runoff contributes more than 20% of the total biochemical oxygen demand (BOD) to the Bay. Short-term biochemical oxygen demand (BOD) is a measure of organic material in the water readily available to bacteria as food.

- A substantial part of the heavy metal load, as well as other toxicants, is associated with the suspended solids. Surface runoff contributes more that 20% of the total suspended solids to the Bay excluding Delta outflow. Total suspended solids is solid material which is able to remain in suspension, even in still water.

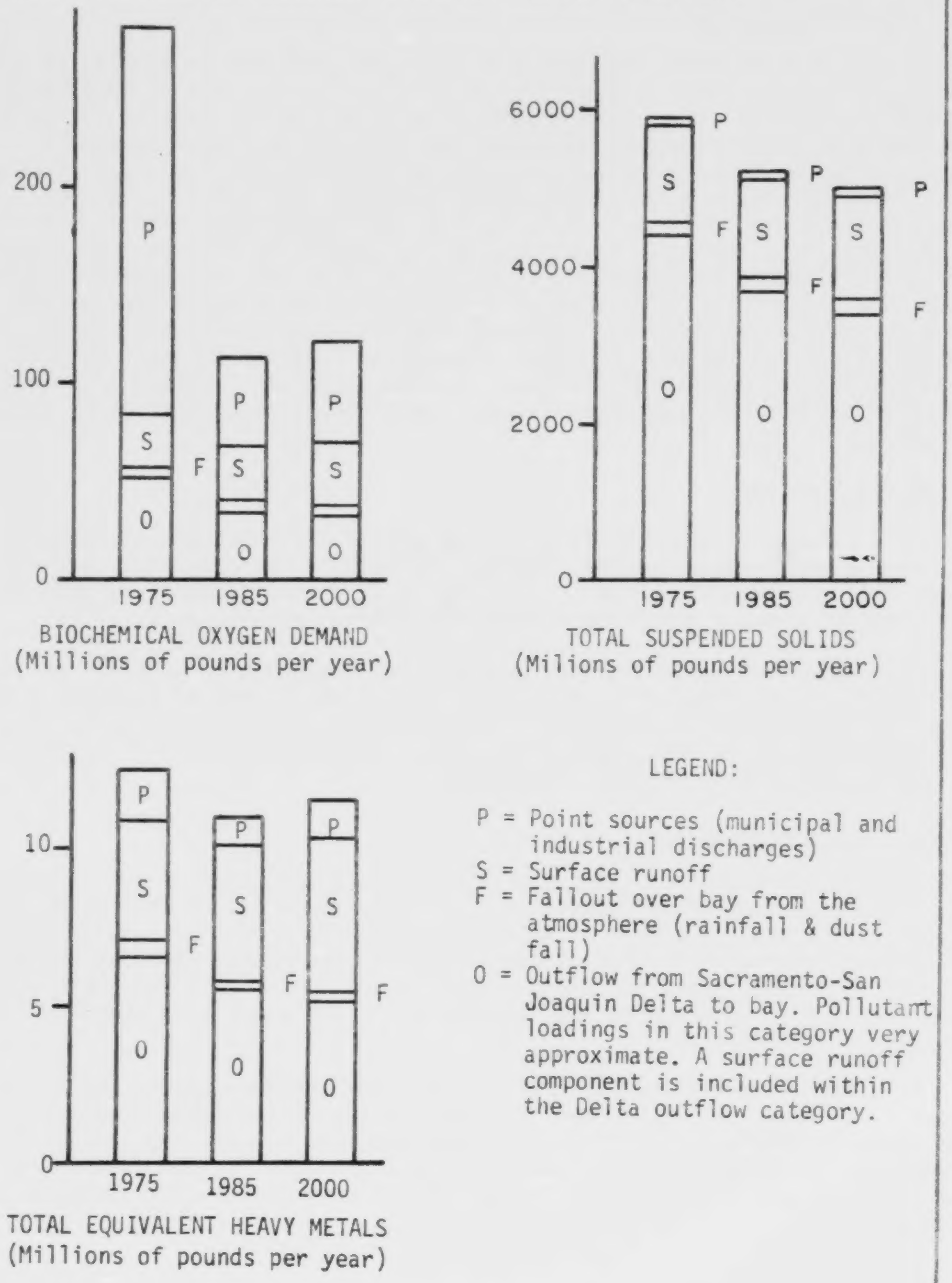
- Surface runoff contributes more than 35% of the total equivalent heavy metals to the Bay excluding Delta outflow. Total equivalant heavy metals is a weighted composite measure of the amounts of eight reasonably common toxic metals.

A comparison between urban runoff average concentrations and treated sanitary sewage effluent point source average concentrations shows that the concentrations of heavy metals, suspended solids, and biochemical oxygen demand, are all higher in the runoff than the treated sanitary sewage effluent. Therefore, urban runoff may have more important short-term effects on San Francisco Bay than treated sanitary sewage effluent.

The annual amounts for the different pollutant sources indicate potential long-term problems. However, the cause-and-effect relationships between these waste discharges and problems in the receiving water is often poorly understood. The short-term effects of urban stormwater runoff on receiving waters occur (by definition) during and immediately following a runoff event: short-term effects are associated with instantaneous concentrations.

The above discussion is significant in that for a receiving water affected by both point source and non-point source pollutants, additional improvements in treatment of point sources may not be as cost-effective as additional control of non-point sources, particularly urban runoff. This is especially true for lead, because urban runoff contributes most of the lead discharged into San Francisco Bay. If non-point source pollution could be controlled, it may insure that the benefits of the billions of dollars being expended for point source controls will be fully realized in terms of fishable, swimmable waters (Congressional Research Service, November 1980).

FIGURE 1-1 SOURCES OF POLLUTANTS ENTERING SAN FRANCISCO BAY.



BIOCHEMICAL OXYGEN DEMAND
(Millions of pounds per year)

TOTAL SUSPENDED SOLIDS
(Milions of pounds per year)

TOTAL EQUIVALENT HEAVY METALS
(Millions of pounds per year)

LEGEND:

P = Point sources (municipal and industrial discharges)
S = Surface runoff
F = Fallout over bay from the atmosphere (rainfall & dust fall)
O = Outflow from Sacramento-San Joaquin Delta to bay. Pollutant loadings in this category very approximate. A surface runoff component is included within the Delta outflow category.

Source: ABAG,1978

Description of Study Area

Castro Valley is an unincorporated community within Alameda County. The project's study area (Figure 1-2) was a 2.4 square mile portion of this unincorporated area. The study area was 1542 acres with primarily residential land use with urban, suburban and rural terrain. The uppermost portion of the watershed (above Seaview Gaging Station) consists of about 633 acres of rural area which is slowly being replaced with suburban residential development. This portjon of the study area also has the most topographic relief. The change in elevation from the upper runoff monitoring station to the lower Knox Gaging Station (a distance of 2.4 miles) is about 200 feet. The 909 acres of urban study area are primarily residential land use. The majority of the residential area consists of single-family housing. The estimated residential population density is about 20 people per acre. Commercial land use is about 7%, and the remaining land is made up of a mixture of open space and institutional land uses. In the 909 acre urban study area, there were 51.7 curb miles of public streets.

Hydrologic Features

Climate of the area is under the marine influence of San Francisco Bay and the Pacific Ocean. The Mediterranean climate is characterized by a dry summer followed by a wet winter with irregularly spaced, frontal rainstorms, with over 90% usually occurring between October and April.

Important aspects of the project were dependent on rainfall and resultant runoff. In a normal rain year, there are about 63 days of measurable rainfall. Normal annual rainfall is about 21 inches. During project field activities there were an average of 60 days per year of measurable rainfall with 18 inches the first year and 23.5 inches the second year.

Study Area Characteristics

For this project, the most relevant chracteristics of the urban area were: the condition of the street surfaces, the types and conditions of gutters, topography and traffic. Most of the streets were asphalt and in fair condition. The gutters were mainly concrete, and the curbs were mostly vertical (rather than rolled). The upper areas had steep slopes, while the lower study areas were relatively flat. A more detailed description of the study area characteristics is provided in Appendix A.

Average daily traffic (ADT) volumes for the two major arterial streets in the study area were 24,000 vehicles per day for Castro Valley Boulevard (which runs north-to-south) and 19,500 for Redwood Road (which runs west-to-east). ADT volumes for the seven collector streets were about 3500 for the entire urban test area. ADT volumes for the minor residential streets of the urban study area were about 1000.

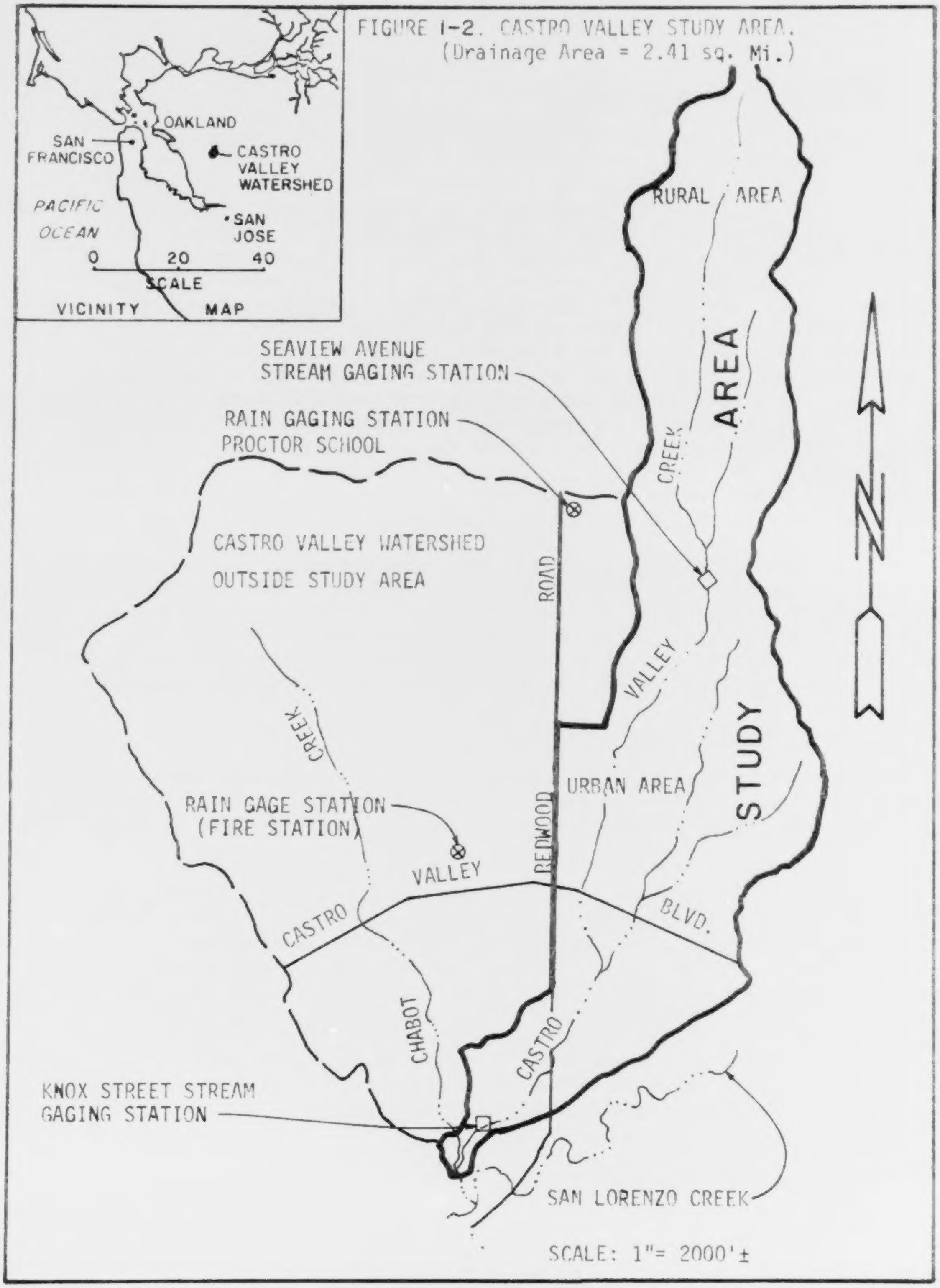


FIGURE 1-2. CASTRO VALLEY STUDY AREA.
(Drainage Area = 2.41 sq. Mi.)

OAKLAND
SAN FRANCISCO
CASTRO VALLEY WATERSHED
PACIFIC OCEAN
SAN JOSE
0
20
40
SCALE
VICINITY MAP
RURAL AREA
AREA
STUDY
N
SEAVIEW AVENUE STREAM GAGING STATION
RAIN GAGING STATION PROCTOR SCHOOL
CASTRO VALLEY WATERSHED OUTSIDE STUDY AREA
ROAD
REDWOOD
CREEK
VALLEY
CASTRO
URBAN AREA
CREEK
CHABOT
RAIN GAGE STATION (FIRE STATION)
CASTRO VALLEY BLVD.
KNOX STREET STREAM GAGING STATION
SAN LORENZO CREEK
SCALE: 1"= 2000'±

Sources of Urban Runoff Pollutants

This section briefly reviews the important sources of urban runoff pollutants. The source of urban runoff are as many and as varied as the different classifications of land in a watershed. The source that can be controlled by street cleaning is obviously the streets. Road dust and dirt quality is effected by vehicle wear (e.g., brake and clutch linings), drips and spills from vehicles (e.g., gasoline and oils) and exhaust products. It is difficult to identify a small number of activities that contribute most of the significant urban runoff pollutants. Urban landscaping practices potentially affecting urban runoff include vegetation, litter, fertilizer, and pesticide uses. Animal wastes also affect urban runoff quality. Road dust and associated automobile use activities contribute most of the lead in urban runoff. Road dust contaminated by tire wear products contributes most of the zinc to urban runoff. Electroplating or other industrial processing activities contribute cadmium. Much of the mercury released into the environment comes fron natural sources in the Bay area. The relative contribution of each of these potential urban runoff pollutant sources is therefore highly variable, depending on specific site conditions and seasons.

An important information need for urban runoff studies is to know the relative contributions from different pollutant sources in the watershed to the volume of runoff at the outfall or outfall yield. Sources that are further from the storm drainage system require overland flow and have a very low yield of most pollutants when compared with parking lots or street surfaces which are impervious and located adjacent to the drainage system (hydraulically connected).

Street Dust and Dirt Pollutant Sources

Automobile tire wear contributes most of the zinc to urban runoff and it is mostly deposited on street surfaces and adjacent areas. Exhaust particulates, fluid losses, and mechanical wear products can all contribute lead to street dirt.

Automobile exhaust particulates contribute many important metals, the most notable of these being lead. Solomon and Natusch (1977) studied automobile exhaust particulates. They found that the exhaust particulates existed in two distinct morphological forms. The smallest diameters range from 0.2 to 0.5 microns. Because they are small, they can become lodged in the lungs and thus are harmful. The second major form of automobile exhaust particulates are large, being about ten to twenty microns in diameter. They further found that 50 to 100 percent of the emitted lead is associated with these large particles, which would be deposited within a few meters of the emission point onto the roadway because of their aerodynamic properties.

As part of this project, street dirt samples were collected, composited and submitted to a laboratory for chemical analysis. Little variation in chemical quality by season or location was found in the street dirt. Figure 1-3 shows the selected pollutant makeup of one ton of Castro Valley street dirt. The analysis also showed that the smaller particles usually had higher concentrations of most of the pollutants. The median particle size for the contaminants was several hundred microns. The greater abundance of the larger particulates (in the 200 to 400 micron size range) increases their importance because of the ability of street cleaning equipment to more effectively remove particles in this size range, than the smaller but less common particle sizes.

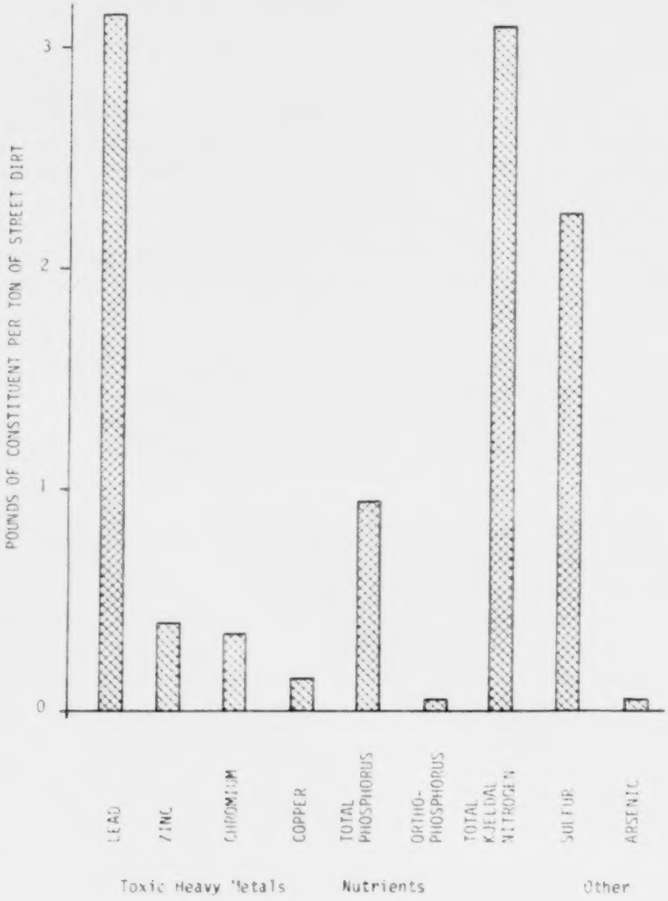


FIGURE 1-3. SELECTED STREET DIRT CHEMICAL QUALITY
CASTRO VALLEY, CA

Receiving Water Measurements

The major objective of this study was to estimte the effects of street cleaning on receiving water quality. An average of about 25 storm periods with an average duration of about two days each occurred in each of the two project years. The durations of the storms ranged fro jusst one hour to as many as 15 days during the test period. the accumulatio periods (i.e., dry periods between storms) rasnged from 12 to 172 dry days preceding each storm. During the first yeat, about 85 percent of the total urban runoff was monitored. During the second year, about 94 percent of the total urban runoff was moniroted. A total of 22 complete datea sets were monitored furing the two year period. A data set was comprised of complete rainfall and runoff monitoring data (quality and quantity) and street surface particulate loading measurements before and after the rain event.

Comparisons of Water Quality with Criteria

One obvious way to determine whether there is a water quality problem in Castro Valley Creek is to compare its water quality concentrations with the various water quality criteria. As Table 1-1 indicates, there is a problem in the creek during wet weather. During base flow conditions (dry weather) there is little difference in the water quality between the rural and urban monitoring stations on the creek. However, during storm water conditions significant removals (control) of pollutants would be necessary in order to meet the standards.

Another method to estimate reductions of pollutants in the runoff is to compare the urban runoff unit area annual discharge to the upstream non-urban area unit discharge. For the urban area unit discharges to correspond to the rural unit area discharges then about 70% of the nutrients, heavy metals and solids would need to be controlled.

No analyses of dissolved constituents were conducted as part of this study, but some were conducted in Castro Valley Creek from November, 1978 to April, 1979 by Metcalf and Eddy Engineers (Lager, 1979). The earlier monitoring showed that most of the alkalinity and total Kjeldahl nitrogen observed was dissolved, while most of the copper, lead, and zinc was in unsoluble forms. Just because the metals are in insoluable forms does not imply that they are unable to pose potential problems.

Street Cleaner Performance

Most of the street cleaning tests on this project were conducted using a modern, mechanical, four-wheel brush-type street cleaner that had dual gasoline engines and hydraulic controls. The speed during the cleaning program was about five to eight m.p.h. The operating speed of most street cleaners is in the range of four to eight miles per hour. Broom replacement and other maintenance wee conducted on a scheduled basis. Because of the nature of this project, the specific operating conditions were held constant during the study program and were not varied.

Castro Valley Street Cleaning Effectiveness

Several street cleaning frequencies were evaluated during the first project year. The second project year, however, used constant street cleaning frequency of 5 times per week for one month followed by two months with no street cleaning operations at all. This enabled the streets to become as dirty as they were likely to become during the first month and then remain at that level during the second month of no cleaning.

Project results showed that, when the streets were dirtiest (initial loadings of about 1000 or more pounds per curb mile), the cleaning efficiency was about 40%. Even though the range of percentage removal values varies appreciably, the residual (after street cleaning) loading values could not be lower than about 200 pounds per curb mile, even with very intensive cleaning.

After about two to three passes per week, there is very little improvement in either initial or residual street surface loadings. Under these cases, the streets are about as clean as they are likely to get by street cleaning operations and any more frequent street cleaning is unproductive. It is much more cost effective to decrease the street cleaning efforts in areas with appreciably dirtier streets such as industrial areas.

In addition to evaluating street cleaning frequencies, a comparison was made between two different generic types of equipment. This was done in order to provide information to public works officials concerned about replacing their street cleaners. It is not recommended to change generic types of equipment because there was not enough performance difference observed under the test conditions to justify purchase of one type versus others.

Control of Urban Runoff

This portion summarizes the costs, effectivenesses and potential uses of various urban runoff control measures. Obviously, street cleaning can only be applied to those impervious areas that street cleaning equipment can reach. Inlets and storm sewerage system maintenance can only affect the material that accumulates in them. Treatement at the outfall, however, is capable of affecting pollutants originating from all sources.

Results

The urban runoff yield information was compared to the specific street surface initial loading values for each constituent. This analysis showed that a maximum of about 20 percent of the total solids and about 35 percent of the lead could have been prevented from reaching the receiving water. If maximum urban runoff improvements are going to be realized by street cleaning, then the streets should be cleaned during the winter months between adjacent storm periods. As expected, lead shows the greatest potential for control by street cleaning equipment, followed by total solids and then arsenic. Figure 1-4 illustrates this relationship and further shows that after about three passes per week, any more street cleaning is unproductive.

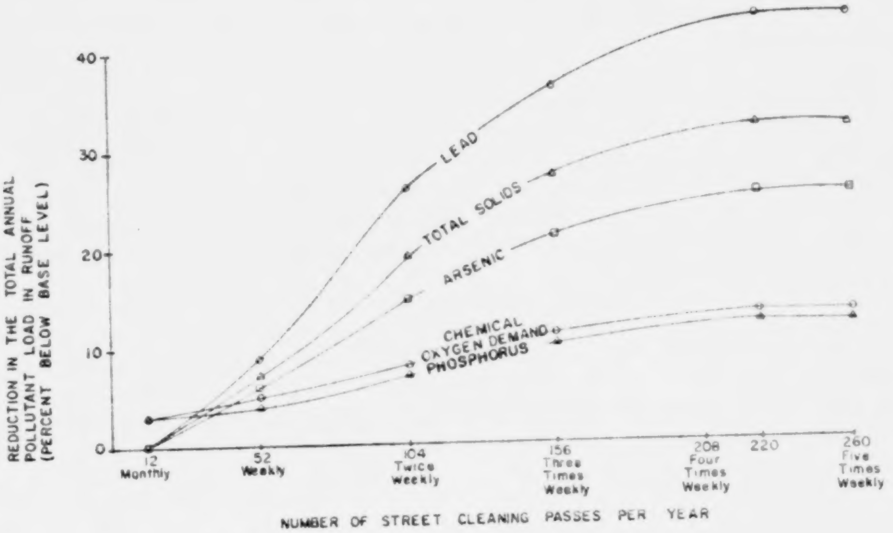


FIGURE 1-4. IMPROVEMENT IN URBAN RUNOFF QUALITY AS A FUNCTION OF STREET CLEANING EFFORT

Total urban runoff control costs could be reduced by at least 25 percent by conducting the most frequent street cleaning efforts immediately before the first rain of the year and during the winter months. Summer street cleaning activities could be substantially reduced in order to meet water quality considerations of street cleaning programs. The cost to remove a unit of contaminant from the street surface increases with increased street cleaning. However, the cost to prevent a unit of contaminant from entering the receiving water did not follow the same pattern during the period of testing. This pattern is very dependent on specific rainfall patterns and for different pollutants.

Figure 1-5 shows that after an initial steep rise in unit cost, going from zero to twice-a-month street cleaning, the unit costs actually decrease. That is, the cost required to prevent a pound of material from reaching the receiving water decreases. After the frequency exceeds about three times per week, however, the unit costs increase again. If the program costs can be justified in terms of water quality, cleaning three times a week between the winter storms may give the best return for the money for total solids. Given the climatic pattern in the Bay Area, it would be more appropriate to schedule the most intensive street cleaning activities before the first major storms of the year, which typically occur in October. The street cleaning effort could then be reduced during the duration of the winter and then significantly reduced during the summer months.

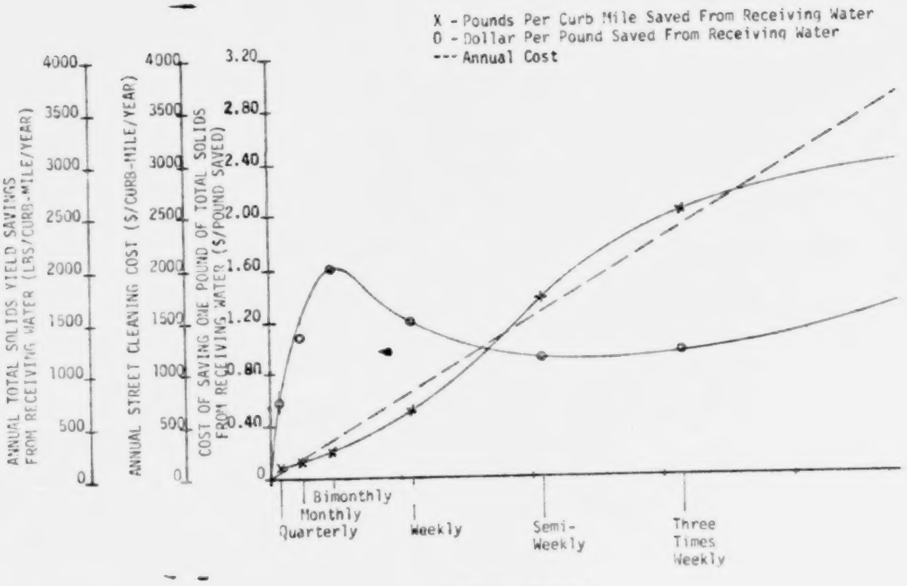


FIGURE 1-5. UNIT COST EFFECTIVENESS OF CONTROLLING URBAN RUNOFF TOTAL SOLIDS BY STREET CLEANING

SECTION 2

SOURCES OF URBAN RUNOFF POLLUTANTS

This section reviews the important sources of urban runoff pollutants based on both literature reviews and field studies conducted as part of this Castro Valley project. An understanding of the sources of important urban runoff pollutants is necessary before an urban runoff control plan can be designed. This information is also necessary when attempting to determine the impact that various street cleaning programs can have on urban runoff water quality, as was done for this project.

This section discusses sources of pollutants from major urban areas and the chemical composition and strengths from various pollutant sources, i.e., paved and unpaved areas and roof tops. Street pollutant sources and their chemical composition and strengths are discussed along with the accumulation and deposition rates. Street inlets and landscaping activities are also mentioned. Apart from the pollutant sources discussed in this section, the relative chemical constituents and their concentrations in the Castro Valley Creek are listed for the base and storm flows from which yields of street area particulates are developed.

Pollutants from Major Urban Areas

Important sources of problem pollutants are related to various uses and processes. These include natural sources, such as rock weathering to produce soil, groundwater infiltration, volcanoes, and forest fires. Automobile use usually affects the road dust and dirt more importantly than other particulate sources of street runoff. The road dust and dirt quality is affected by vehicle fluid drips and spills (such as gasoline and oils), gasoline combustion and vehicle wear products. Local soil erosion and pavement wear products can also significantly contribute to street surface particulates. Urban landscaping practices potentially affecting urban runoff include vegetation debris and fertilizer and pesticide uses. Animal wastes also affect urban runoff quality. Other sources of urban runoff pollutants that may be important in specific cases include firework debris, wildlife and sanitary wastewater infiltration. The quality of rain, snow and atmospheric dust fallout are all affected by urban particulate resuspension after initial deposition. Many manufacturing and industrial activities also affect urban runoff quality, especially settleable air pollutants. Therefore, it is extremely difficult to identify a small number of activities that contribute most of the significant urban runoff pollutants.

Some relationships between sources and specific pollutants are evident. Natural weathering and erosion products of rocks contribute the majority of the hardness and iron in urban runoff. Road dust and associated automobile use activities contribute most of the lead in urban runoff. In certain situations, paint chipping can also be a major source of lead. Urban agricultural activities can be a major source of cadmium. Electroplating and ore-processing activities may also contribute cadmium.

Many pollutant sources are also specific to a particular area and ongoing activities. Iron oxides, for example, are associated with welding operations and strontium, used in the production of flares and fireworks, would probably be found on the streets in greater quantities around holidays, and/or at the scenes of traffic accidents. The relative contribution of each of these potential urban runoff pollutant sources is therefore highly variable, depending on specific site conditions and seasons.

An important information need for urban runoff sources studies is the relative contributions from different pollutant sources in the watershed to the outfall yield. Sources that are far from the storm drainage system and require considerable overland flow have a very low yield of most pollutants when compared with parking lots or street surfaces which are impervious and located adjacent to the drainage system (hydraulically connected). Those areas that are further away from the drainage system require directed or sheet flows of the runoff to pass over pervious areas. This increases the infiltration of the polluted waters into the soils and enhances their uptake by vegetation along the drainage routes. Barriers can also cause ponding and settling of polluted sediments from the runoff. All of these factors significantly act to prevent the contaminated particulates from reaching the receiving waters. However, during large storms, especially when the ground is saturated, the erosion of these now contaminated soils can significantly degrade urban runoff quality. In addition, the resuspended contaminated street surface particulates (by wind and automobile induced turbulence) can be redeposited in adjacent non-paved areas. These street surface particulates that contaminate the nearby soils reduce the quantity of street surface particulates directly affecting the receiving waters. These redeposited street surface particulates can be washed into the receiving water during periods of high erosion.

Pervious landscaped and vacant areas can make up about half of the total urban areas in the south San Francisco Bay area. However, because of the typically dry conditions in this area, and the distance that these urban runoff sheet flows must travel before reaching the drainage, only about 5% of the rainfall falling on these areas is expected to contribute to the outfall flow. Therefore, very little of the pollutants from these areas is expected to affect the outfall yield. Rooftops, which may be 15 to 20% of the south Bay area urban areas, are also located a relatively long distance from the storm sewerage system. Since the roof drainages are not directly connected to the storm sewerage in this area, they may require considerable overland flow.

The effective yield from rooftops is expected to be about 30%. Sidewalks, however, make up about 5% of these urban areas and are located adjacent to the storm drainage system. Some of their drainage is directed towards adjacent pervious areas, however. Therefore, only about half of the runoff from sidewalks enters the receiving waters. Parking lots in the south Bay urban areas make up about 7% of the area, and are mostly paved and impervious. Some of the runoff from these parking areas is directed towards adjacent pervious areas, and again, only about half of the parking lot runoff is expected to reach the receiving waters. Street surfaces, however, are located close to the storm drainage system and make up about 15 to 20% of the urban areas. Most of the runoff originating from the streets is expected to reach the outfall except for infiltration through streets in poor condition, and because of evaporation.

Strengths of Source Area Particulates

Table 2-1 presents the results of a study conducted as part of this project which collected representative dry particulate samples from many areas in the urban and non-urban areas of the Castro Valley Creek watershed. These samples included soil samples in the rural area upstream of the urban area in addition to soil samples collected in vacant lots in the urban area. Urban residential construction sites and unpaved driveways and parking lots were also sampled, along with soils from residential lawns, school turfs, residential gardens and landscaped parks. Samples from impervious paved areas were also collected by vacuuming. These samples were from urban driveways, parking lots, school playgrounds, and of course, the typical city streets in the study area. Rural road, highway, and airport samples were obtained and analyzed in a previous study (Pitt and Amy, 1974). Various residential and commercial rooftop particulate samples were also collected and analyzed. These samples represent all of the exposed pervious and impervious areas in the area. Additional soil samples were collected in the non-urban upstream areas to examine background soil quality.

These particulate samples were analyzed for several major urban runoff pollutants: lead, zinc, chemical oxygen demand, total kjeldahl nitrogen and ortho-phosphates. These samples were also analyzed for asbestos fiber concentrations, which is described in Section 8 of this report. Many of the urban dry source area particulate samples had concentrations greater than the rural soil concentrations. The lead concentrations observed were about 30 to 2000 mg/kg in the test area, while the general lithosphere rock and soil averages about 10 to 15 mg/kg. The maximum values for lead in "natural" soils can be as high as 200 mg/kg. The lowest zinc concentrations (about 70 to 100 mg/kg) were about twice as high as the average lithosphere rock and soil concentrations but well within the total range observed. The observed ortho-phosphate concentrations in the study area were all much less than the reported ranges in typical soils. The concentrations of most of the constituents shown in this table increase when the source is more urbanized.

TABLE 2-1. STRENGTHS OF CASTRO VALLEY SOURCE AREA PARTICULATES (mg constituent/kg total solids)

	Constituents				
Source Area:	Lead	Zinc	Chemical Oxygen Demand	Total Kjeldahl Nitrogen	Ortho-Phosphate
Unpaved Areas:					
Rural vacant lot-1	33	70	14,000	900	16
Rural vacant lot-2	53	123	83,000	2,100	19
Rural vacant lot-3	110	203	35,000	1,400	21
Rural vacant lot-4	34	91	43,000	2,400	5
Urban vacant lot-1	36	192	18,000	1,200	58
Urban vacant lot-2	180	127	28,000	1,100	18
Urban resid. const. site	47	90	25,000	160	19
Urban driveways	286	194	29,000	800	5
Urban parking lots	260	178	37,000	500	5
Residential lawns	220	154	103,000	3,000	30
School turf	666	205	410,000	11,000	393
Residential gardens	87	108	66,000	2,100	41
Landscaped park	70	122	80,000	1,800	10
Paved Areas:					
Driveways	640	172	59,000	1,300	11
Parking lots	1,140	392	73,000	900	8
School Playground	360	322	38,000	600	6
Typical city streets	1,900	300	86,000	640	5
Rural road (1)	65	70	49,000	500	-
Highway (1)	500	190	46,000	650	-
Airport taxiway and runway (1)	110	75	-	-	-
Rooftops:					
Resid., wooden shingles, 20 yr. old	1,450	470	26,900	2,900	2
Resid., asphalt shingles, 1, yr. old	950	440	6,450	690	4
Resid., asphalt shingles, 1 yr. old	780	330	48,500	2,800	80
Commercial composites of asphalt, wood and tar & gravel	1,000	370	7,860	940	5

(1) Source: Pitt and Amy, 1973. (Bay Area values)

A notable exception is the relatively high concentration observed in school turf area. The lead concentration there was about one-third of the observed lead concentrations for urban street surface particulates. The reasons for these high, school turf concentrations are not known. Rooftop lead and zinc particulate concentrations were also relatively high, possibly indicating wind transport of heavily contaminated street surface particulates for significant distances.

Street Dust and Dirt Pollutant Sources

Much of the field and laboratory work associated with this Castro Valley urban runoff project involved collecting and analyzing street surface particulate samples. The field and laboratory procedures used in collecting these samples are described in Appendix B. These samples were collected to enable comparisons between street surface loading values and runoff water yields to be made. In addition, these street surface particulate samples, which were also collected before and after each street cleaning activity in the test area, also enabled the effectiveness of the street-cleaning equipment to be monitored. These relationships are discussed in the following sections of this report. This sub-section reports the observed chemical strengths of the street surface particulate values.

Most of the street surface dust and dirt material by weight are local soil erosion products, while some materials are contributed by motor vehicle emissions and wear. Minor contributions are made by erosion of street surfaces in good condition. The specific make-up of street surface contaminants is a function of many conditions and varies widely.

As mentioned previously, automobile tire wear ultimately contributes most of the zinc to urban runoff, and it is mostly deposited on street surfaces and nearby adjacent areas. About half of the airborne particulates lost due to tire wear settle out on the street and the remaining particulates settled within about 6 meters of the roadway. Exhaust particulates, fluid losses (drips and spills) and mechanical wear products can all contribute lead to street dirt. Many other heavy metals are also important pollutants associated with automobile activity. Most of these automobile pollutants affect parking lots, street surfaces, and driveways. Some materials contaminate adjacent areas, due to wind transportation after resuspension of the particulates from the road surface, or by direct deposition after emission.

Automobile exhaust particulates contribute many important heavy metals to street surface particulates and to urban runoff and receiving waters. The most notable of these heavy metals is lead. Solomon and Natusch (1977) studied automobile exhause particulates in conjunction with a comprehensive study of lead in the Champaign-Urbana, Illinois area.

They found that soil lead concentrations were higher near the roads and homes. This indicated the capability of road dust and peeling paint to contaminate nearby soils. The lead content of the soils ranged from 130 to 1200 mg/kg. Koeppe (1977), as part of another element of this Champaign-Urbana lead study, found that lead was tightly bound to various soil components. However, the lead did not remain in one location, but it was transported both downward through the soil profile and to adjacent areas through both natural and man-assisted processes.

Chemical Strengths of Street Dust and Dirt

As mentioned previously, an important element of this Castro Valley urban runoff project was the sampling and analyses of street surface particulates. Table 2-2 presents the observed street dirt chemical strengths, expressed on a milligram of constituent per kilogram total solids basis (mg/kg) for both study periods. The study area was divided into three test areas during the first year to obtain more detailed information on pollutant accumulation, street cleaning effectiveness, and chemical quality as a function of the observed topographic and socioeconomic conditions. However, during the second year the complete basin was studied as a unit to enable a more complete range of basin-wide street surface loading conditions to occur.

Appendix C shows the observed street dirt chemical qualities for all composited samples submitted to the laboratory for testing. This information is summarized in Table 2-2 by test area, chemical constituent for each project year. The variations in observed chemical qualities within these sub-groupings was quite small, with relative standard deviations (the standard deviation divided by the sample mean) being small. The overall observed range for lead concentrations varied from 540 to 2400 mg/kg with a two-year average of about 1600 mg/kg. These concentrations are based on a total sample weight which was calculated from the individual particle size concentrations shown in Appendix C. There was little variation in chemical quality by season or location, within the study areas. The information presented in Appendix C shows a consistency in chemical quality for the different size ranges. It was also observed that the smaller street surface particulate sizes typically contained the highest concentrations of most of the contaminants. However, the median particle size for the contaminants (where half of the pollutant loadings were associated with particle sizes below and above this size) typically was several hundred microns in diameter. Therefore, even though the strength of the very small particulates was so much greater than for the larger particulates, the greater abundance of the larger particulates increase the importance of these larger particle sizes. This is especially important considering that street cleaning equipment is much more effective in removing the larger particle sizes.

TABLE 2-2. STREET DIRT CHEMICAL QUALITY (mg. constituent/kg. total solids)

	LEAD				ZINC			
	First Year			Second Year	First Year			Second Year
	Lower Area	Middle Area	Upper Area	Complete Basin	Lower Area	Middle Area	Upper Area	Complete Basin
Minimum	1154	1463	542	1063	215	206	113	169
Maximum	2188	2368	1437	2328	497	298	269	312
Mean	1580	1770	1180	1570	287	253	222	222
Standard Dev.	243	235	176	241	58	24	37	29
St. Dev./mean	0.15	0.13	0.15	0.15	0.20	0.09	0.17	0.13

	VOLATILE SOLIDS				ARSENIC		COPPER		CHROMIUM	
	First Year			Second Year						
	Lower Area	Middle Area	Upper Area	Complete Basin	First Year	Second Year	First Year	Second Year	First Year	Second Year
Minimum	47,000	45,000	38,000	62,000	4.3	8.5	31	61	120	98
Maximum	116,000	146,000	122,000	111,000	29	23	94	108	286	153
Mean	74,000	68,000	82,000	75,000	16	12	73	85	239	127
Standard Dev.	19,000	29,000	25,000	13,000	6.2	4.5	10	15	51	18
St. Dev./Mean	0.25	0.42	0.30	0.18	0.39	0.37	0.14	0.18	0.21	0.14

	COD		SULFUR		PHOSPHORUS		ORTHO PHOSPHATE		KJELDAHL NITROGEN	
	First Year	Second Year	First Year	Second Year	First Year	Second Year	First Year	Second Year	First Year	Second Year
Minimum	33,000	72,000	354	1040	169	432	18	18	--	1440
Maximum	158,000	150,000	1800	1420	622	594	49	29	--	1950
Mean	91,000	92,000	1030	1220	462	481	39	21	--	1550
Standard Dev.	22,000	23,000	290	99	80	48	6.6	2.7		142
St. Dev./Mean	0.24	0.25	0.28	0.08	0.17	0.10	0.17	0.13	--	0.09

The observed chemical strengths of the street surface particulates in this study were compared to the strengths of the street surface particulates collected nationwide and as summarized in a previous report (Pitt, 1979). The nationwide mean lead strength for street surface particulates was about 1800 mg/kg, with a range of 0 to 10,000 mg/kg. This agrees quite closely to the value of about 1600 mg/kg observed in Castro Valley. Castro Valley zinc and chemical oxygen demand concentrations were about one-third lower than the nationwide mean, the copper and chromium values were about the same, and the kjeldahl nitrogen values were about one-half of the nationwide mean values. However, all of the values observed for Castro Valley were well within the ranges observed nationwide.

Street Surface Particulate Accumulation and Deposition Rates

An important objective of the Castro Valley runoff project was to measure the street surface particulate deposition and accumulation rates in the test areas. This information is necessary before an effective street cleaning program can be designed. The rate of street surface contaminant accumulation between adjacent street cleaning activities and rains must be known in order to control the maximum street surface contaminate loadings for any cleaning or rain frequency. This information was also necessary to compare expected before-storm street surface loadings with the Castro Valley urban runoff mass yields. The rainfall that occurred during the two-year study was examined and those periods in which rains removed an unknown quantity of street surface contaminants were eliminated from the accumulation rate calculations. To determine the accumulation rates, each observed street surface loading value was related to an accumulation period (the time since the street was last cleaned or a significant rain occurred which was capable of removing most of the street surface contanimants from the streets). The accumulation rates were determined both on a particle size basis and for all of the contaminants studied.

During the two-year period of study, about 90 days had measurable rains. About half of these rain days had significant rains. These significant rains may add material to the street surface through erosion of adjacent areas. A significant rain for the Castro Valley area was defined as one of 0.2 inches total rain, or more, within about one day, irrespective of traffic conditions. Rains with peak 5 minute intensities of 0.5 inches per hour, irrespective of traffic considerations, or rains with average intensities of 0.1 inches per hour or greater, with moderate to heavy traffic were also considered significant. Rains and traffic conditions which met one of these criteria were capable of imparting enough energy to the street surface to loosen contaminants. They could also supply enough water to flush them along the street surface and gutters to the storm sewerage inlets. If sufficient amounts of water were not available to carry the particulates through the storm sewerage and to the outfall, the particulate material was deposited in the sewerage system. Rains of about one-half inch total were found to be capable of transporting much of the material through the storm drainage system. Storms between one-half and one inch could easily remove previously deposited material from the sewerage while rains greater than about one inch, especially during saturated soil conditions, were capable of causing significant erosion from the surrounding pervious areas.

Figure 2-1 presents a figure showing the street surface loading values for lead between October 1979 and March 1980. This figure shows that the lead accumulation rate and the resultant loading would have been much higher without the street cleaning activity. This is one possible way to show the cause and effect relationship between reduced street surface loadings and changes in runoff water quality. This figure resembles the classical sawtooth pattern which is created by manmade or natural losses of street surface particulates and then the initial rapid and then slower accumulation of particulates on the street surface. Periodic decreases in street surface loadings were observed not associated with street cleaning or rainfall conditions. It is thought that these removals were caused by high winds. Winds greater than about 13 mph have been shown capable of removing particulates from the street surface, even in the absence of traffic induced turbulence (Cowherd, et al, 1977).

Figure 2-2 shows the calculated street surface deposition and accumulation curves for Castro Valley. Figure 2-3 shows these curves for three divisions of the study area for the first year of study. The loading values observed and the associated time periods since last cleaned or significant rain were analyzed using computer curve fitting routines. Again, loading values that were affected by small rains were eliminated from this analysis. Because of erosion material deposition on streets after large rains and wind and traffic induced losses from street surfaces, a larger than desirable error is always associated with these deposition and accumulation rate calculations. However, the initial street surface loading values after small to moderate rains or street cleaning is quite well-known because of the large number of data points for these values and the reduced exposure period for these other removal processes to occur. In addition, the heaviest loading values that are likely to occur on the streets are also fairly well-known, but are defined by fewer data points and are obviously affected by winds. The resulting loading values and deposition and accumulation rates are quite different for each test area. Table 2-3 summarizes these values for total solids for both years and all test areas.

Appendix C contains similar accumulation loading and deposition summaries for the other contaminants studied. The loading values observed did not level off during the period of study. However, the accumulation rates did substantially decrease with time. The lower test area had appreciably greater accumulation rates and loading values than the middle and upper test areas, while the upper test area had the lowest values. The deposition rates, equal to the first day accumulation periods, were 80, 70 and 30 lbs/curb-mile/day for the lower, middle, and upper areas, respectively. The overall basin deposition rate for the second year was about 40 lbs/curb-mile/day. The accumulation rate equals the deposition rate minus the removal rate. The deposition rate is a function of the characteristics of the area, such as climate, land use, traffic and

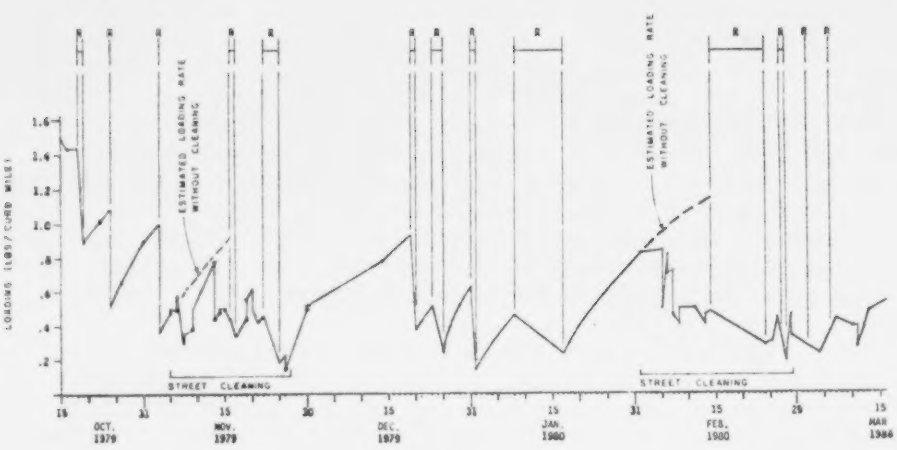


FIGURE 2-1. STREET SURFACE LEAD LOADING VALUES
AS A FUNCTION OF TIME

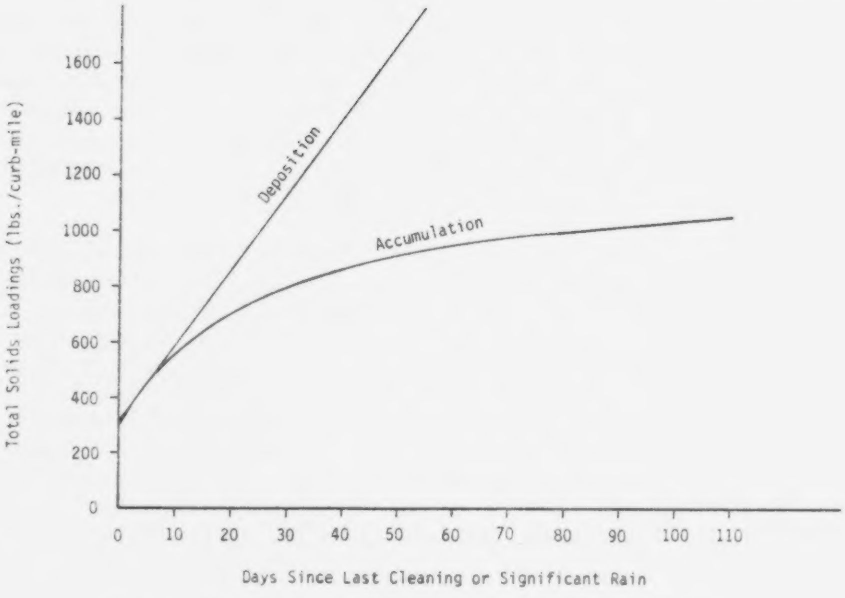


FIGURE 2-2. DEPOSITION & ACCUMULATION CURVE - TOTAL AREA - YEAR TWO

FIGURE 2-3. CASTRO VALLEY DEPOSITION AND ACCUMULATION CURVES - 1st YEAR

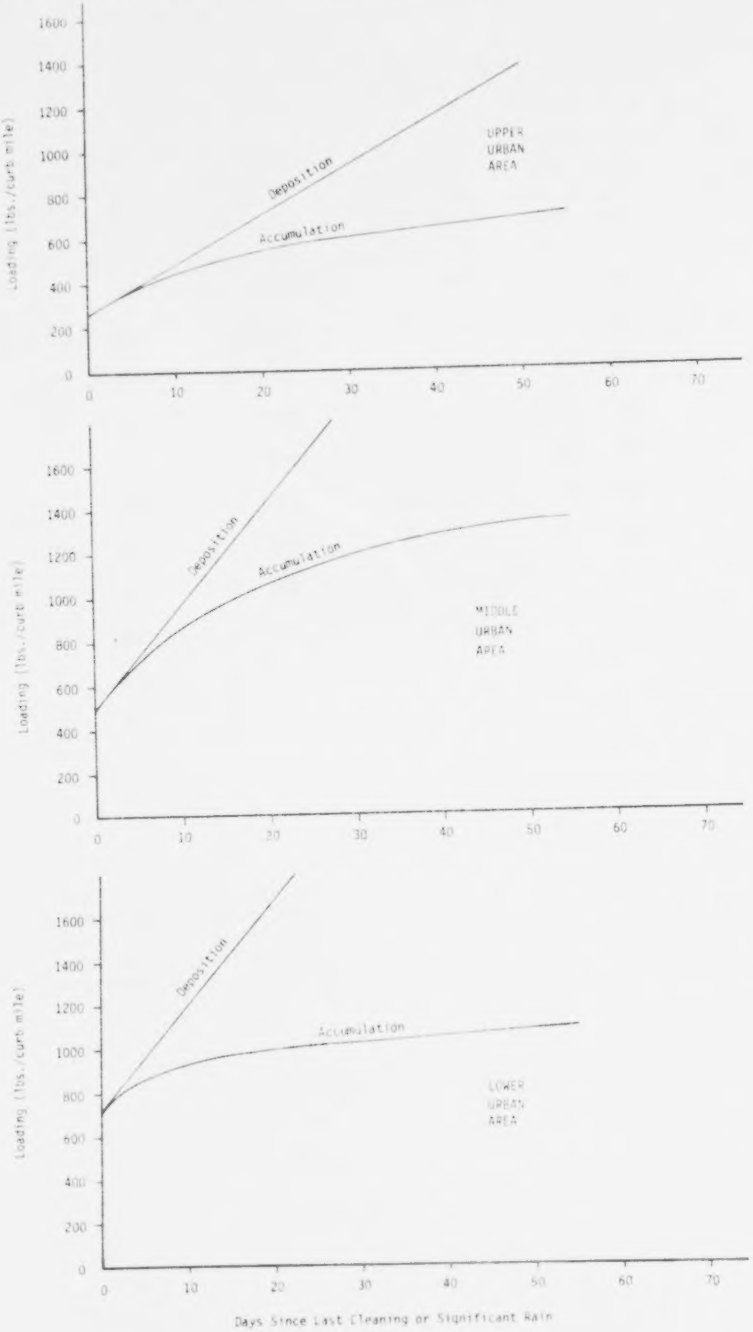


TABLE 2-3. CASTRO VALLEY LOADING, DEPOSITION AND ACCUMULATION VALUES FOR TOTAL SOLIDS

Days After Street Cleaning or Significant Rain	First Yr. Lower Area		First Yr. Middle Area		First Yr. Upper Area		Second Yr. Complete Area	
	Ldg. Value (1)	Accum. Rate (2)	Ldg. Value (1)	Accum. Rate (2)	Ldg. Value (1)	Accum. Rate (2)	Ldg. Value (1)	Accum. Rate (2)
0	700	-	500	-	260	-	300	-
1	780	80	570	70	290	30	340	40
3	870	45	660	45	330	20	400	30
5	910	20	710	25	360	15	460	30
7	940	15	760	25	400	13	510	25
10	980	13	840	25	440	12	570	20
20	1,040	6	1,070	23	530	9	710	14
30	1,080	4	1,200	13	590	6	790	8
55	1,125	2	1,330	5	680	4	930	6
75	-	-	-	-	-	-	1,000	4
110	-	-	-	-	-	-	1,060	2

(1) Loading (Ldg.) value units are lbs/curb-mile.

(2) Accumulation rate units are lbs/curb-mile/day, for the time period from the preceeding time to the time shown. As an example, the value shown for 20 days is the average accumulation rate for the time period 10-20 days after cleaning or significant rain. In addition, the first accumulation rate shown (for the 0 to 1 day period) is estimated to be the deposition rate.

most importantly, street surface conditions. The removal of the contaminants can be accomplished either by street cleaning or naturally by rains or winds. The difference between the accumulation and deposition rates at any one time is lost from the street surface by wind or traffic-induced turbulence. This material can become suspended in the air, but most of this material settles within about three meters of the roadway (Pitt, 1979).

The initial loading values immediately after street cleaning and rains were greater in the lower test area, and least for the upper test area. Significant rains were found to produce cleaner street surfaces in the lower and middle test areas when compared to the values after street cleaning, but in the upper test area, street cleaning resulted in cleaner streets than did significant rains. This is probably because of the steeper slopes in the upper area, and the greater erodability of those soils contributing to erosion loads on the streets after most rains.

The confidence intervals of these accumulation rate values were wide, but reasonable, considering the influencing factors and the sampling constraints. Approximately 50 to 80% of all of the "initial" data points fell on the same initial values, ∓50 lbs. This error was in a range of 7 to 20% of the absolute initial values. The mid-range accumulation data points fell within 12 to 30% of the indicated mean values. The data points in the upper accumulation range were within 10 to 25% of the indicated mean value. About 50 to 60% of all of the data points during the first year were within an accumulation period of 0 to 5 days. About 30% were between 5 and 25 days for mid-range accumulation values and the upper values of greater than 25 days accumulation had between 10 and 16% of the data points. During the second year, however, more of the data points were in the lower range (84%) and only 12% were in the mid-range of 5 to 25 days and only 4% were for accumulation time periods greater than 25 days. During the first year, 31 to 37 accumulation data points were used to construct the accumulation curves in the three test areas, while 67 data points were used for the second year calculations.

Inlet Particulate Quantities and Chemical Strengths

Table 2-4 presents an estimate of the amount of material present in Castro valley strom drainage inlets, based upon Alameda County Flood Control observations in Oakland (Shawley, 1980). The Oakland study examined twenty residential storm drain inlets in September 1979. These inlets were typically clened once every year to once every two years. an average of about sixty pounds of dry particulates was found in each inlet. Assuming a total of about 200 inlets in the Castro valley study area (based on an estimate of

TABLE 2-4. ESTIMATES OF INLET CONTRIBUTIONS TO ANNUAL STORM FLOW

Constituent	Total load per inlet (dry lbs.)(1)	Total load for 200 inlets (dry lbs.)(2)	Total load for 200 inlets as a percentage of annual runoff yield	Relative strength of inlet solids(1) (mg. constituent per kg. tot. sol).	Median inlet particle size(1) microns
Total Solids	60	12,000	2%	-	2,300
COD	10	2,000	1.5	155,000	1,660
TKN	0.02	4	0.1	320	1,780
Total Phosphorus	0.08	16	2	1,360	1,750
Lead	0.06	12	2	1,070	1,710

(1) Based on observations of 20 inlets in Oakland residential areas in September, 1979 that are cleaned about once per year. Source: Shawley, May 1980.

(2) Based on an estimate of about 0.25 inlets per urban residential acre, or about 4 inlets per urban residential curb-mile, and 909 acres and 51.7 curb-miles in the study area.

about one-fourth of an inlet per residential area acre, or about four inlets per residential area curb mile), about 12,000 pounds of dry particulates may be residing in the Castro Valley inlets at any one time. This 12,000 pounds is about 2% of the total annual runoff yield. It is not known how fast this material accumulates in the inlets, or at what frequency it is washed out. If this material was not removed, much of it could eventually contribute to the runoff yield. If the storm sewerage inlets were cleaned more frequently, it is quite possible that the total quantity of material in the inlets at any one time would not change. It is expected that equilibrium loading conditions are reached relatively quickly and would be maintained. However, very large storms which may occur once a year or so could be expected to totally scour out the inlets and sewerage. As a maximum, the inlets could possibly be cleaned several times a year with corresponding direct urban runoff pollutant savings. It is doubtful, however, if more than about a 10% reduction in total solids, phosphorus, lead and COD would be possible by inlet cleaning. The relative costs of inlet cleaning compared to street cleaning and other potential control measures are also discussed in Section 6 of this report.

The observed relative strengths of the inlet solids expressed in milligrams of constituent per kilogram total solids (mg/kg) basis are within the range of reported street surface particulate chemical strengths. The inlet particulate COD strengths are about 50% greater than for the street dirt, while the total kjeldahl nitrogen values are about one-fifth of the street dirt strengths. The total phosphorus values were about three times the observed mean street dirt strengths, while the inlet lead particulate strengths were about 50% less than the mean street dirt strengths. Much of this variation in observed strengths between the inlets and the street surface particulates can quite easily be explained because the one-time inlet sampling effort conducted in late summer in an adjacent city was compared to the two-year comprehensive sampling effort conducted in Castro Valley. The median inlet total solids particle size was about 2300 microns, which was substantially greater than the median total solids particle size for street dirt (about 500 microns). This substantiates the belief that the inlets are most effective in capturing the larger particle sizes. These larger particle sizes most typically have lower pollutant strengths associated with them. However, because these inlet samples were obtained in late summer, and were quite wet, a substantial amount of leaching of the materials to more soluble forms and bio-degradation may have occurred since they were deposited.

Urban Landscaping Activities as Sources of Urban Runoff Pollutants

Vegetative litter may be a significant runoff component from almost all source areas. The fallen leaves on Castro Valley streets are an important street surface pollutant in the fall months. Special leaf removal activities have to be used to help control these large quantities of leaves to prevent the storm sewerage from becoming clogged. Fertilizer and pesticide use is mostly associated with landscaped areas, but large amounts of pesticides are sometimes used to control plant growths in impervious areas. Fertilizers may be used in large quantities for road maintenance operations. Koeppe (1977) found that significant levels of plant available lead may be released during decomposition of plant tissues. Therefore, it may be difficult to permanently immobilize soil lead if polluted plant residues are returned to the soil. These polluted plants are usually found close to roads and have accumulated large amounts of lead in their foliage. Limited movement of lead during plant decomposition may be the cause for the downward movement of lead through the soil column.

Animal feces may contrib ute important quantities of nutrients and bacteria to the runoff. These mostly affect vacant land and landscaped areas where domesticatedpets are encouraged to visit. Some cities, however, have animal control ordinances which require the owners to pick up any feces left by their pets. In many large cities this may substantially reduce the quantity of bacteria and nutrients in the urban runoff.

Atmospheric Resuspension, Transportation, and Redeposition of Urban Runoff Particulates

Atmospheric processes affecting urban runoff pollutants include dry dust fall and precipitation. One must be careful in interpreting this atmospheric deposition data because of the ability of many polluted dust and dirt particles to be resuspended and then redeposited within the urban area. In many cases, the measured atmospheric deposition measurements include material that was previously residing and measured in other urban runoff pollutant source areas (such as street surfaces). Therefore, mass balances and determinations of urban runoff deposition and accumulation from different source areas can be misleading unless the transfer of materials between source areas and the effective yield of this material to the receiving water is considered.

Relative Concentrations of Base and Storm Flows in Castro Valley Creek

Table 2-5 groups the constituents by ranges of relative concentrations at these two sampling locations for both base flows and storm runoff. This simple summary points out the major differences in water types during base flows and storm runoff. During base flows, the water is quite hard and is mostly made up of the major water components, calcium, sodium, chloride and sulfate. However, during storm runoff conditions, the water becomes noticably softer and filterable solids and chemical oxygen demand become much more important than during base flows. In addition, almost all of the heavy metals increase their relative concentrations in storm runoff by several orders of magnitude when compared to base flow conditions. Appendix E-19 and E-20 summarize the observed contaminant relative concentrations in both the base flows and storm flows at the Seaview and Knox Stations in Castro Valley Creek. About five base flow measurements and about 30 flow-weighted total storm measurements were obtained at each of the two stations.

When these relative concentrations in the runoff are compared to the street surface relative concentrations, it becomes obvious which constituents in the urban runoff are mostly associated with street surface washoff, and which are associated with erosion materials. Lead, arsenic and chromium are mostly in the urban runoff because of the street surface particulates, while sulfur and ortho-phosphates originate in non-street surface areas. Zinc, volatile solids, copper, chemical oxygen demand, total phosphorus, and total kjeldahl nitrogen may also come from erosion of non-street surface areas.

Yields of Street Area Particulates to Urban Receiving Waters

As previously mentioned, past studies have resulted in watershed atmospheric deposition rates that were substantially greater than the total urban runoff yield. The extra atmospheric deposited material was accumulated in the soils, vegetation, and organisms, and was not washed off during rain events. The washoff yields of the different constitutents were compared with various rain characteristics as part of this study to determine the relative yield of street surface loadings to the runoff water quality. Generally, the larger rainfall volumes, especially with relatively short accumulation periods between the rain events, resulted in a small relative contribution of the street surface particulates to the total runoff particulate yield. During these conditions, the street surfaces are relatively clean (because of the frequent rains), and these larger rains resulted in greater erosion from the surrounding saturated pervious areas. In addition, eroded material was deposited on the streets during the rains, with some of it remaining on the streets after the storms ended.

TABLE 2-5. GROUPINGS OF CONSTITUENTS BY RELATIVE CONCENTRATION RANGES

Relative Concentration Range (mg. const./kg. total solids)	Base Flow		Storm Runoff		
	Seaview	Knox	Seaview	Knox	Urban
>500,000	Total Hardness Filterable Solids	Total Hardness Filterable Solids	Non-filterable Solids	Non-filterable Solids	Non-filterable Solids
100,000 - 500,000	Total alkalinity Non-carbonate hardness Calcium Chloride Sulfate	Total alkalinity Non-carbonate hardness Calcium Chloride Sulfate	Total alkalinity Total hardness Filterable solids COD	Total alkalinity Total hardness Filterable solids Volatile, non-filterable solids COD	Total alkalinity Total hardness Filterable solids Volatile, non-filterable solids COD
10,000 - 100,000	Magnesium Non-filterable solids COD	Magnesium COD	Non-carbonate hardness Calcium Magnesium Sodium Chloride Sulfate Volatile, Non-filterable solids Iron	Non-carbonate hardness Calcium Magnesium Sodium Chloride Sulfate Iron	Non-carbonate hardness Calcium Magnesium Sodium Chloride Sulfate Total Nitrogen Iron
1,000 - 10,000	Potassium Volatile,non-filterable solids Total nitrogen Organic nitrogen Total Kjeldahl nitrogen Dissolved ortho-phosphates Iron	Potassium Non-filterable solids Volatile. non-filterable solids Total nitrogen Total Kjeldahl nitrogen Nitrites, plus nitrates	Potassium Total nitrogen Organic nitrogen Total Kjeldahl nitrogen Nitrites, plus nitrates	Potassium Total nitrogen Organic nitrogen Total Kjeldahl nitrogen Nitrites, plus nitrates Total phosphorus Dissolved, ortho-phosphates Lead	Potassium Organic nitrogen Total Kjeldahl nitrogen Nitrites, plus nitrates Total phosphorus Dissolved, ortho-phosphates Lead Zinc
100-1,000	Ammonia Nitrites plus Nitrates Total phosphorus	Organic Nitrogen Ammonia Total phosphorus Dissolved, ortho-phosphates Iron	Ammonia Total phosphorus Dissolved, ortho-phosphates Lead Zinc	Ammonia Copper Zinc	Ammonia Copper Nickel
10-100	Lead Zinc	Lead Zinc	Chromium Copper Nickel	Arsenic Chromium Nickel	Arsenic Chromium
1-10	Arsenic Chromium Copper	Arsenic Chromium Copper	Arsenic Cadmium	Cadmium Mercury	Cadmium Mercury
<1	Cadmium Mercury Nickel	Cadmium Mercury Nickel	Mercury		

For rains with moderate intensities and larger periods of accumulation (resulting in quite dirty street surfaces and dry surrounding soil conditions before the rains) almost all of the urban runoff yield was associated with street surface washoff. During less intense storms, the amount of traffic is important. Large amounts of traffic can supply needed energy to the street surface to loosen particulates, but a smaller rain may not be adequate to flush the solids through the storm sewerage system. If small storms occur at night, or at other times of low traffic, then much smaller amounts of street dirt material would be loosened and transported along the street and gutter system than for similar rains during heavier traffic conditions. Therefore, estimates of yields from different source areas in the watershed are very site dependent and must consider antecedant weather conditions along with specific storm characteristics.

Appendix Table D-3 presents the street surface loads, washoffs, and urban runoff yields for the twenty-two monitored storm sets observed during this project. These twenty-two monitored storms were selected for analyses because all of the runoff at both monitoring stations was sampled between, before and after street surface loading samples. These twenty-two storms cover a wide range of storm types. This table shows the loading on the street surfaces immediately before and after each storm. It also shows the change in street surface particulate loadings and the observed runoff yield at the monitoring stations. The ratios between the before and after street surface loads are also given, along with the ratio between before street surface loads and the storm yield and the ratio of the differences of the street surface loadings before and after the storm to the yield.

A variety of storm characteristics were statistically compared with these different ratios in an attempt to determine the most significant and simple relationship. Figure 2-4 is the selected relationship which relates the street surface load immediately before the monitored rain event, the total runoff yield observed, and the total runoff volume (in acre-feet) for the urban area (909 acres). This shows that for very large storms, most of the material is not originating on the street surface for almost all of the constituents. Small storms with a total volume of less than fifty acre-feet, however, had much of their runoff material associated with before storm street surface loadings. If the storm volumes were greater than about 100 to 150 acre-feet, the ratios were very consistent and much lower.

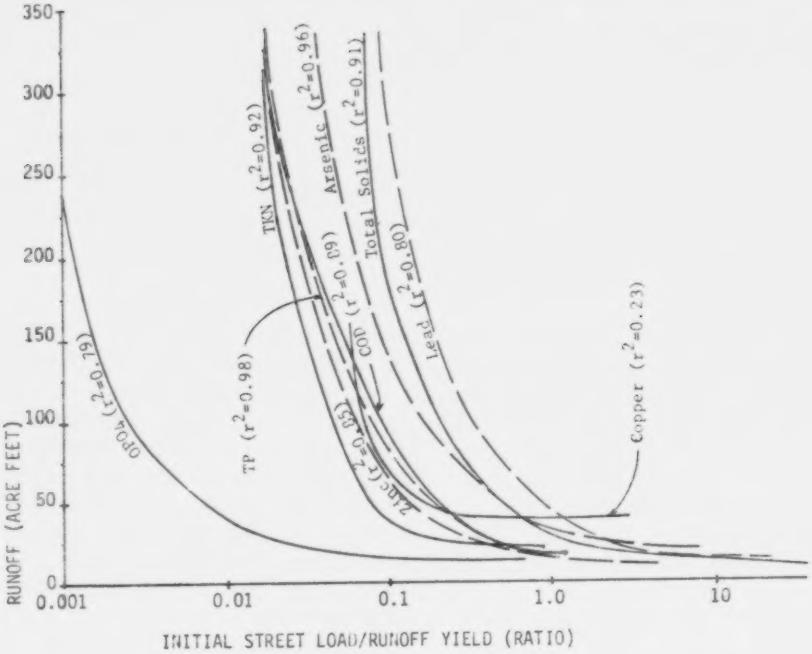


FIGURE 2-4. STREET LOAD AND RUNOFF RATIOS AS A FUNCTION OF RUNOFF VOLUME.

Table 2-6 summarizes these values and shows the relatively high r^2 values obtained from this curve-fitting routine (implying good fitting curves). Expressing this ratio as a function of total urban runoff volume in acre-feet was important because this runoff volume considers antecedant moisture conditions in the watershed, rainfall intensities and durations all in a simple measure. Many other elements were examined independently in multiple-variable analyses, but no simple model with such good r^2 values was obtained. Ratios of initial street loadings to urban runoff yields of one or greater implies that most of the observed runoff yield could be accounted for by street surface washoff alone. If the ratio is greater than one, however, it implies that not all of the street surface particulate material was washed off the street, or at least much of it was retained in the sewerage system and did not reach the outfall. Ratios less than one imply that material from non-street surface areas contributed most of the urban runoff yield during that storm event. Section 3 presents detailed information relating the distribution of urban runoff volumes, rain totals and runoff coefficients for different seasons of the year.

TABLE 2-6. INITIAL STREET LOADING COMPARED TO URBAN RUNOFF QUANTITY AS A FUNCTION OF RUNOFF VOLUME

Runoff Volume (Acre-Foot)	Initial Street Load/Runoff Yield (1)								
	Total Solids	Arsenic	Copper	Lead	Zinc	COD	TP	OPO_4	TKN
325	0.080	0.044	<0.06	0.10	0.020	0.020	0.020	<0.001	0.020
250	0.085	0.054	<0.06	0.12	0.025	0.024	0.024	0.001	0.020
150	0.13	0.095	0.060	0.20	0.044	0.054	0.044	0.0017	0.034
100	0.22	0.16	0.090	0.35	0.062	0.095	0.080	0.0026	0.045
50	0.50	0.50	0.16	0.90	0.13	0.20	0.20	0.0080	0.075
25	1.2	2.0	>1	2.0	0.36	0.45	0.50	0.020	0.20
10	15	>10	>10	20	3	3	3	>1	>1
r2 Value	0.91	0.96	0.23	0.80	0.85	0.89	0.98	0.79	0.92

(1) dimensionless ratio, both street load and runoff yield expressed in lbs. per total watershed area.

SECTION 3

RECEIVING WATER MEASUREMENTS

This section reviews the rain and runoff quantities monitored during the project along with the characteristics of base flow and wet weather flow including the mass yields of the various pollutants. It also provides comparisons of the water quality with the established standards and discusses the level of control necessary in order for the water to meet the standards.

Important elements of the study on Castro Valley Creek were:

(1) to estimate the beneficial effects of street cleaning on the quality of runoff and receiving waters and

(2) to investigate the quantity of pollutants removed from the watershed by various types of storms.

In addition, a few samples were collected of the Castro Valley Creek sediments both above and within the urban area. These observed urban and rural sediment qualities were compared to get an idea of the long-term degradation in Castro Valley Creek associated with urban feeder creek runoff. Castro Valley Creek does not receive any point discharges, but a very limited amount of sewage overflows and cross connections may occur during extreme runoff events. The upstream, non-urban area is actually a developing area; several homes were being constructed at the time during both project years. However, as described in Appendix A, a runoff monitoring station (Seaview) was located at the boundary between this upstream non-urban, but developing area, and the downstream mature urban area. This station began monitoring runoff on December 5, 1978. The Knox Street station also began monitoring runoff on this date and was located at the bottom of the urban study area, just before Castro Valley Creek discharged into another urban feeder creek draining a larger urban area.

Rains and Runoff Quantities

Appendix E presents illustrations of hydrographs for all the storms used in the data analysis.

Appendix E-1 presents the rain history for the Castro Valley test area during both project years which shows the date that the rain occurred, the total quantity of rain and its duration. In addition, the average and peak fifteen minute rain intensities are shown. Table 3-1 summarizes the monthly rain occurrences during the two project years. An average of about 25 storm periods per year occurred, with an average duration of about two days each. March had the largest number of storm periods (five) and the rain season was restricted to November through April. A much smaller amount of rain occurred in October and May. The first rains of the rain year, usually occuring in October, can be quite important, as they can have a large

TABLE 3-1. SUMMARY OF CASTRO VALLEY RAIN CONDITIONS FOR BOTH PROJECT YEARS (1978-1979 and 1979-1980 RAIN YEARS)

Month	Avg. No. of Storm Periods per Month	Avg. Total Rainfall per Month (in.)	Avg. Rainfall per Storm Period (in.)	Range of Rainfall per Storm Period (in.)	Avg. Duration of Storm Period (days)	Range of Duration of Storm Period (days)	Avg. Accumu. Period Before Storm Period (days)	Range of Accumu. Period Before Storm Period (days)
October	2	1.38	0.69	0.01-1.69	0.6	0.01-1.2	88	4-172
November	3	2.22	0.74	0.05-1.96	1.3	0.5 -3.4	34	2-170
December	2.5	2.76	1.10	0.36-3.52	4.5	1.4 -12.5	11	3-24
January	4.5	5.30	1.18	0.01-4.34	1.7	0.01-8.7	6	1-16
February	3.5	5.82	1.66	0.01-5.93	3.7	0.01-15	12	1-28
March	5	2.15	0.43	0.01-1.98	1.2	0.01-4.5	9	2-19
April	3.5	1.05	0.30	0.01-1.06	0.4	0.01-0.9	10	2-19
May	1	0.08	0.08	0.01-0.14	1.2	0.01-2.3	13	9-16
June	<1	<0.01	<0.01	-	<0.01	-	-	-
July	<1	<0.01	<0.01	-	<0.01	-	-	-
August	<1	<0.01	<0.01	-	<0.01	-	-	-
September	<1	<0.01	<0.01	-	<0.01	-	-	-
Annual	Total 25	Total 20.76	Avg. 0.77	0.01-5.93	Avg. 1.8	0.01-15	23	1-172

rainfall. In addition, the streets can be quite dirty in early October because of the long preceding dry period (average of 88 days). The range of the rainfall per storm period ranged from one hundredth of an inch to almost six inches during the period of study, but averaged about three-fourths of an inch. The durations of the storms ranged from one-hour to as long as fifteen days during the test period. The accumulation periods ranged from one to 172 days preceding each storm.

As shown in Section 6, the important relationship observed between street surface loading values and runoff yields were dependent upon the urban runoff volume, expressed in acre-feet. Appendix E-2 presents the average and range of runoff volumes observed during the two project years, on a monthly basis. It also shows the runoff coefficients (the ratio of runoff volume to rainfall volume). The largest average rainfall volumes occurred in February, with storms having as much as 340 acre-feet of runoff. All the months however (except for December) had rain events that were so small that no runoff was observed. The corresponding runoff coefficients also varied widely from month to month, again with the largest coefficient observed in February with a high of about 0.76. This is a very large runoff coefficient, even for an urban area, indicating highly saturated soil conditions. A more typical runoff coefficient for rains with runoff was about 0.3. The smallest rains that may have occurred during June through September did not create any observed runoff.

Table 3-2 summarizes the monitoring effort during both project years. During the first year, about 72% of the total rain was monitored, which accounted for about 85% of the total urban runoff flow. During the second year, a better performance was obtained with 86% of the total rainfall monitored, corresponding to 94% of the total urban flow monitored. The monitoring activities included complete flow-weighted sampling of the runoff events, with many chemical analyses performed. Table 3-3 lists those rains which were not monitored, along with the corresponding significant accumulation periods and the urban creek flows in acre-feet.

The rainfall quantity and urban runoff flows were monitored for all rains. This table also shows the monitored storms that most closely resembled the rainfall and runoff characteristics of the storms which were not monitored. These corrections were used later in this sub-section to determine corresponding annual runoff yields. Because such a large fraction of the total runoff was monitored, these corrections were quite small in most cases, when compared to the total expected urban runoff yields. A total of about 22 rain periods were monitored during both project years. Each rain period was defined by a period of time when all urban runoff was monitored, sampled and analyzed between adjacent street surface monitoring, at both runoff stations. Some rain periods were made up of several individually monitored, but adjacent rain events. This was necessary because the streets may not have dried sufficiently to sample between the rains. These rains are fully described in Appendix E.

TABLE 3-2. SUMMARY OF MONITORING EFFORT

Month	Total Rain (in)	Rain Monitored	Rain Causing Runoff (in)	Rain Causing Runoff Monitored	Total Urban Flow (acre-ft.)	Urban Flow Monitored
Nov., 1978	2.23	0	2.19	0	30.1	0
Dec.	0.81	0	0.81	0	10.4	0
Jan., 1979	6.44	5.25	6.39	5.25	225.0	203.3
Feb.	4.94	4.58	4.83	4.58	157.9	150.6
March	2.77	2.73	2.73	2.73	44.5	44.5
April	0.65	0.37	0.57	0.37	8.5	6.8
May	0.15	0	0.05	0	1.9	0
Total, year 1	17.99	12.93 (72%)	17.57	12.93 (74%)	478.3	405.2 (85%)
Oct., 1979	2.75	0.99	2.67	0.99	72.1	19.8
Nov.	2.21	2.12	2.12	2.12	73.8	73.8
Dec.	4.71	4.71	4.71	4.71	171.4	171.4
Jan., 1980	4.15	4.12	4.12	4.12	110.5	110.5
Feb.	6.69	6.68	6.68	6.68	365.6	365.6
March	1.53	1.46	1.46	1.46	44.5	44.5
April	1.45	1.45	1.45	1.45	39.3	39.3
Total, year 2	23.49	20.14 (86%)	21.82	20.14 (92%)	877.2	824.9 (94%)
Total, project	41.48	33.07 (80%)	39.39	33.07 (84%)	1355.5	1230.1 (91%)

TABLE 3-3. RUNOFF YIELD CORRECTIONS FOR RAINS NOT MONITORED

Rains not monitored:

Dates	Inches Rain	Sign. Accum. Period (days)	Urban Creek Flow (acre-ft.)	Closest Monitored Storm in Character
11/12-14/78	0.27	(very long)	1.2	#14
11/19-22	1.92	6	28.9	M
12/1	0.36	10	5.3	N
12/17	0.39	16	3.7	N
12/18	0.06	1	1.4	0
1/3/79	0.10	17	0.9	14
1/7-8	0.34	21	10.5	16 + 17
1/9	0.18	< 1	4.4	0
1/17	0.24	2	5.9	0
2/23-24	0.18	< 1	4.7	0
2/25-26	0.07	2	2.6	0
4/16-17	0.09	20	1.0	14
5/6-7	0.05	10	1.9	14
10/25	1.68	6	52.3	12 + 13

Observed Base Flow and Urban Runoff Concentrations

This project was concerned with total mass flows of pollutants in the creek at the two stations and by subtration, the total quantity of urban runoff pollutants entering the creek for various levels of street cleanliness and rain conditions. In order to maximize the number of monitored events, composite sampling and restricted analyses were necessary. Automatic water samplers directly connected to flow measuring devices were used at the two runoff monitoring stations to enable flow-weighted composite samples to be automatically obtained. Samples for any storm could then be directly combined into a single flow-weighted sample representative of the total mass flows during the storm. Analyzing a single sample simplified the analyses and significantly reduced the costs to determine the total pollutant mass flows that occurred during the runoff event, as compared to obtaining much more expensive discrete sampling data.

The runoff measuring devices were not calibrated (stage-flow curves were not available) for the first several storms, so these first storms required collecting many discrete samples throughout the storm periods, and then individually analyzing each sample. These monitored discrete concentrations, which are representative of different time periods in the storms, were later used to calculate mass flows when accurate flow calibrations were available. The first storm samples involved analyzing ten discrete samples spread over the period of the runoff flow period. The next two runoff events were sampled utilizing an estimated stage-flow relationship, enabling a significant reduction in the amount of samples necessary and the associated costs. Additional storms during the first year and throughout the second year were analyzed using the final stage-flow relationship and were analyzed on a total storm flow-weighted composite basis. A rather complete list of chemical constituents were monitored for each sample. Specific conductance, turbidity and pH measurements were also made on each individual, discrete and flow-weighted sample throughout the project period. These results are presented in Appendix E.

Appendix E-3 summarizes the observed water quality conditions in Castro Valley Creek during base flow conditions at both the Seaview and the Knox stations. These were based on five, 24-hour composite samples conducted approximately monthly during the winter season of the second project year. Appendix E-4 summarizes the observed Castro Valley Creek storm flow concentrations at both runoff stations. From nineteen to thirty flow-weighted composite analyses were conducted at the Knox station and fourteen to twenty analyses were conducted at the Seaview station. Fewer samples were analyzed at Seaview because several of the initial storms in both rain years did not produce any flow at the upstream Seaview location because the dry and more pervious area absorbed all of the rain. Appendix E-5 summarizes the observed storm urban runoff mass emissions at the Seaview and Knox stations and the calculated mass emissions for urban runoff only. The specific storm-by-storm information is presented in Appendix E.

Runoff Mass Yields

Appendix E-6 shows the ratios between the urban storm mass yields and the non-urban storm mass yields, based on a pounds per acre per year basis. In all cases, the average ratios were much greater than 1 signifying that the urban mass yields, on a lbs/acre/year basis were much greater than for the non-urban areas. The ratios were smallest for the major ions, total alkalinity and hardness values.

The ratios however, were very large for the volatile suspended solids and dissolved ortho-phosphates. The unit area mass emissions for the urban area are about 4 to 12 times greater for most of the nutrients and heavy metals when compared to the non-urban area. Appendix E-7 groups the constituents by observed urban to non-urban mass yield ratios. Those constituents (e.g., lead) with the highest ratios were more associated with urban runoff than those with lower ratios.

Urban area annual mass emissions were calculated and are presented in Appendix E-8. The total monitored storms for each year were totalled and additional runoff quantities were added, based upon the storm corrections shown previously in Table 3-3. Most of the annual unit area urban runoff mass emissions observed using this procedure were quite close to the values calculated by Metcalf and Eddy for the total Castro Valley Creek watershed (Lager, 1980). They were also well within the range of observed mass emissions for urban runoff observed elsewhere. It is seen that more than 90% of the zinc and total solids estimated to occur were actually monitored. 87% of the lead was monitored followed by more than 75% of the copper, chromium and COD. A smaller portion of the arsenic, total phosphorus ortho-phosphate and total Kjeldahl nitrogen were monitored because of their lower analytical priorities: Some of the smaller storms did not result in enough sample volume for these tests.

The variation of the base flow yield and storm flow yield as a function of month was also calculated and is shown in Appendix E-9 and E-10. Most of the constituents associated with base flow occurred during the winter months, because the base flows were so much greater between the storm periods than during the drier summer months. About 25% of most of the constituents in base flows occurred during the month of February, while less than 10% of the total base flows occurred during each of the summer months. About 1/3 of the total annual storm yield also occurred in February, with each storm in February averaging about 10% of the total annual yield. During the first project period, significant storms occurred at the very beginning of the rain year with these early October storms accounting for much of the annual total urban runoff. However, when both study periods were combined for analyses, these first storms were not as important. Therefore, one can expect a highly variable distribution of urban runoff flows on a monthly basis for different years. The second project year was noted for very large rains during the month of February. As expected, much less than 1% of the total annual urban runoff occurred during each of the summer dry months.

Appendix E-11 compares the urban base flow and storm runoff annual yields. This shows that significant portions of the major ions, alkalinity, hardness and total dissolved solids total annual yields were associated with the base flow portion. However, the runoff portion of the total annual yield accounted for practically all of ther heavy metals, nutrients, suspended solids and organics.

Comparisons of Observed Urban Runoff and Receiving Water Quality with Various Water Quality Criteria

The easiest indication of whether the observed Castro Valley Creek water quality conditions may be a potential problem, is to compare observed concentrations with published water quality criteria values for various beneficial uses. Table 3-4 summarizes the various water quality criteria for some of the monitored runoff constituents. However, these beneficial use water quality criteria are established mostly for continuous discharge situations, having resultant long term average concentrations in the receiving waters. In addition, these criteria were not established for the specific urban runoff compounds present in urban runoff or for the softwater conditions that occur during runoff periods. In addition, many of the beneficial use criteria shown on this table are not appropriate uses for Castro Valley Creek water. Some of the aquatic life criteria, however, are specific for the hardness of the water and the specific organisms present. The new aquatic life criteria published by the Environmental Protection Agency for toxic pollutants are shown on Table 1-1. These new criteria are given for average 24-hour conditions in addition to maximum concentrations for different hardness values.

These criteria, however, can be used as an indicator of potential problems of urban runoff, if these uses were likely to occur and assuming that the short-term exposures to urban runoff correspond to these typical 3-day average concentrations. Therefore, the potential problems expected, based upon these water quality criteria are a worst-case condition. The actual receiving water impacts would be less than what might be expected based only on these criteria. This is true considering that the criteria for the metals were established for soluble metals only, while most of the measurements were made for total metals. However, just because the heavy metal is not readily soluble upon discharge to the receiving water does not mean that it cannot create a potential long-term problem due to accumulation in the sediments and subsequent bio-transformations or chemical transformations to more soluble and toxic forms. Appendix E-12 and E-13 show the percent of observed base flow and storm flow concentrations that exceeded the various water quality criteria, at both the Seaview and Knox stations. Very little difference is seen between the Seaview and Knox station conditions, especially during base flow conditions. During dry weather, the urban runoff fraction of the base flow is associated with irrigation runoff, car washings, hosing down driveways and infiltration into the storm sewerage from leaking freshwater supplies.

TABLE 3-4. WATER QUALITY CRITERIA FOR VARIOUS BENEFICIAL USES (mg/l)

Constituent	Irrigation	Livestock and Wildlife	Industrial	Aquatic Life (96 hr. exposures)	Marine Life	Recreational Uses	Freshwater Public Supply
Total Alkalinity			< 35 - 500	> 20			
Total Hardness			<120 - 5,000				
Chloride							<250
Sulfate							<250
Filterable Solids (TDS)	500 - 5,000		<150 - 35,000	Narrative			Narrative
Non-filterable Solids (SS)	Narrative*			< 80			
Ammonia, as N				<5 (total NH_3)			
Nitrates, as N and nitrites	Narrative	<100					<10 (NO_3 only)
Total Phosphorus					<0.0001 Elemental P		
Phosphates					<0.0003	<0.3 for streams <0.08 for lakes	Narrative
Arsenic	<0.1						<0.05
Cadmium	<0.01 - 0.05	<50		<0.01**	<0.005		<0.01
Chromium	<0.1 - 1.0	<1.0		<0.1	<0.1		<0.05
Copper	<0.02 - 5.0	<0.5		<0.1**	<0.05		<1.0
Iron				<1.0			<0.3
Lead	<5 - 10	<0.1		<0.2**	Narrative		<0.05
Mercury		<0.001		<0.00005	<0.0001		<0.002
Nickel				<0.01**	<0.01		
Zinc		<25		<0.01**	<0.1		< 5
pH	4.5 - 9.0 desired	6.0 - 9.0 desired		6.5 - 9.0 desired	6.5 - 8.5 desired	5.0 - 9.0 desired	5.0 - 9.0 desired
Temperature(°C)	Narrative	maintain natural pattern	Narrative	<20°C	Narrative	<30°C	Narrative
Turbidity (NTU)				small change		>4 ft. Secchi	Narrative

* Narrative means important constituent for use, but too site, or use specific.

** Estimated aquatic life criteria based on aquatic life that could be present in Castro Valley Creek & water hardness

Sources: McKee and Wolf 1963 USEPA 1973
USEPA 1975 USEPA 1976

Appendix E-15 and E-16 show the control reduction necessary for base flow and stormwater runoff concentrations to meet these criteria. The necessary controls are shown as a percentage removal, compared to the maximum, average and minimum observed concentration. During base flow, there is little difference between the amount of control reduction necessary between the two sampling stations. It is also seen that the base flow water can contain appreciable quantities of problem pollutants. During stormwater conditions, however, many more contaminants are potential problems and greater removals are typically necessary at Knox than at Seaview. In some cases, however, greater controls are necessary at Seaview.

No dissolved constituent analyses were conducted as part of this study but some were conducted in Castro Valley from November, 1978 to April, 1979 by Metcalf and Eddy Engineers (Lager, 1979). Table 3-5 shows the observed total concentrations for total Kjeldahl nitrogen, alkalinity, copper, lead and zinc and the corresponding estimated dissolved concentrations of these constituents based upon the earlier Metcalf and Eddy monitoring. Most of the alkalinity and total Kjeldahl nitrogen observed was dissolved, while most of the copper, lead and zinc was in insoluble forms. As mentioned previously, however, just because the metals are in insoluble forms does not mean they would not cause problems. Appreciable quantities of heavy metals accumulate in receiving water sediments which then affect the water quality at a much later time than the runoff event. Table 3-6 compares the necessary control for total and dissolved lead, copper and zinc at the Seaview and Knox stations during stormwater conditions. The necessary controls, when only the dissolved fraction is considered, are obviously less but still significant in almost all cases.

Table 3-7 compares the observed base flow and storm flow concentrations with the EPA's new toxic pollutant aquatic life criteria. These criteria are based upon the specific hardness of the receiving waters and for average 24-hour and maximum 1-hour concentrations observed. The base flow concentrations can be compared to the average 24-hour criteria. It is still seen that significant decreases in these four key heavy metal constituents may still be necessary even during base flow and storm runoff conditions, irrespective of the specific criteria that is compared.

Another method to estimate necessary controls of urban runoff is to compare the urban runoff unit area annual discharge to the upstream nonurban area unit discharge. Table 3-8 shows the necessary control of the urban runoff for its unit area discharges to correspond to the upstream unit area discharges. If the highest controls are necessary 90 to 99% of the nutrients, heavy metals and solids would need to be controlled. In addition, more than 80% of the major constituents would have to be controlled.

TABLE 3-5. ESTIMATED DISSOLVED STORM WATER QUALITY CONCENTRATIONS (mg/l)*

Constituent	Observed Total Concentrations			Probable Dissolved Concentrations		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Total Kjeldahl Nitrogen:						
Seaview	0.9	14	4.0	0.5	8	2.4
Knox	0.65	7.5	2.1	0.4	4.5	1.3
Alkalinity:						
Seaview	62	200	120	50	160	100
Knox	21	91	43	17	73	34
Copper:						
Seaview	0.030	0.10	0.056	<0.02	<0.05	<0.025
Knox	0.021	0.70	0.10	<0.01	<0.35	<0.05
Lead:						
Seaview	0(1)	0.6	0.11	0	0.1	0.02
Knox	0.1	3.3	0.50	0.05	0.7	0.1
Zinc:						
Seaview	0.06	0.50	0.18	0.02	0.2	0.05
Knox	0.093	2.2	0.31	0.03	0.7	0.1

*Based on Metcalf and Eddy Engineers monitoring in Castro Valley from November 1978 to April 1979 (Lager, 1979):

Constituent:	median observed dissolved/total ratio:
TKN	0.6
Alkalinity	0.8
Cu	<0.5
Pb	0.2
Zn	0.3

(1) "0" values are below the detection limit

TABLE 3-6. COMPARISONS OF NECESSARY CONTROL FOR TOTAL CONSTITUENT AND ESTIMATED DISSOLVED CONSTITUENT (% removal) -STORMWATER CONCENTRATIONS

	Irrigation Criteria (<0.02 - 5 mg/1)				Aquatic Life Criteria (<0.1 mg/1)				Marine Life Criteria (<0.05 mg/1)			
	Total		Dissolved only		Total		Dissolved only		Total		Dissolved only	
COPPER:	Seaview	Knox	Seaview	Knox	Seaview	Knox	Seaview	Knox	Seaview	Knox	Seaview	Knox
Max:	80%	97%	60%	94%	0	86%	0	71%	50%	93%	0	86%
Ave:	64	80	20	60	0	0	0	0	11	50	0	0
Min:	33	5	0	0	0	0	0	0	0	0	0	0

	Livestock Criteria (<0.1 mg/1)				Aquatic Life Criteria (<0.2 mg/1)				Freshwater Supply Criteria (<0.05 mg/1)			
	Total		Dissolved only		Total		Dissolved only		Total		Dissolved only	
LEAD:	Seaview	Knox	Seaview	Knox	Seaview	Knox	Seaview	Knox	Seaview	Knox	Seaview	Knox
Max:	83%	97%	0	86%	67%	94%	0	71%	92%	98%	50%	93%
Ave:	13	30	0	0	0	59	0	0	56	90	0	50
Min:	0	0	0	0	0	0	0	0	0	50	0	0

	Aquatic Life Criteria (<0.01 mg/1)				Marine Life Criteria (<0.1 mg/1)			
	Total		Dissolved only		Total		Dissolved only	
ZINC:	Seaview	Knox	Seaview	Knox	Seaview	Knox	Seaview	Knox
Max:	98%	100%	95%	99%	80%	95%	50%	86%
Ave:	94	97	80	90	44	68	0	0
Min:	83	89	50	67	0	0	0	0

TABLE 3-7. COMPARISONS OF OBSERVED BASEFLOW AND STORM RUNOFF CONCENTRATION WITH NEW EPA "TOXIC POLLUTANT" AQUATIC LIFE CRITERIA (% CONTROL NEEDED)[1]

		BASE FLOWS						STORM RUNOFF						STORM RUNOFF-DISSOLVED					
		Average Criteria			Maximum Criteria			Average Criteria			Maximum Criteria			Average Criteria			Maximum Criteria		
Constituent	Location	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg
Cadmium	Seaview	0	95	75	0	0	0	0	100	98	0	74	0	-	-	-	-	-	-
	Knox	0	95	75	0	0	0	0	100	98	0	50	0	-	-	-	-	-	-
Copper	Seaview	0	70	[illegible]	0	0	0	80	94	89	0	60	29	<70	<88	<76	0	<20	0
	Knox	0	74	14	0	0	0	71	99	94	0	94	60	<40	<98	<88	0	<89	<20
Lead	Seaview	0	87	47	0	0	0	0	97	82	0	33	0	0	80	0	0	0	0
	Knox	0	74	20	0	0	0	79	99	96	0	88	18	60	97	80	0	43	0
Zinc	Seaview	0	50	17	0	0	0	17	90	72	0	0	0	0	75	0	0	0	0
	Knox	0	44	29	0	0	0	46	97	84	0	73	0	0	93	50	0	14	0

(1) New Freshwater Aquatic Life Criteria, published by the EPA (Federal Register November 28, 1980 for toxic pollutants)

Constituent:	24-hr Average	Maximum Concentration
Cadmium	0.00005	0.006
Copper	0.006	0.04
Lead	0.02	1.4
Zinc	0.05	0.6

Units in mg/l with hardness at 200 mg/l as CaCO3.

TABLE 3-8. NECESSARY CONTROL OF URBAN STORMWATER RUNOFF TO EQUAL NON-URBAN STORM WATER RUNOFF (% Control)

Constituent	Based on Annual Yield (lbs/acre/year)		
	Minimum	Average	Maximum
Total alk., as $CaCO_3$		47%	86%
Non-carbonate hardness, as $CaCO_3$		68	91
Total hardness, as $CaCO_3$		55	87
Calcium, diss.		58	88
Magnesium, diss.		47	86
Potassium, diss.		71	94
Sodium, diss.		52	87
Chloride, diss.		64	88
Sulfate, diss.		55	86
Total solids		68	94
Filterable solids (TDS)		71	95
Non-filterable solids (SS)		70	94
Volatile, Non-filterable solids (VSS)		99	100
COD		89	97
Total nitrogen		78	95
Organic nitrogen		87	97
Total Kjeldahl nitrogen		85	96
Ammonia, as N		66	91
Nitrites plus nitrates, as N	23%	87	98
Total phosphorus		84	95
Dissolved ortho-phosphates, as PO_4		93	99
Arsenic	9	83	96
Cadmium		77	94
Chromium		68	90
Copper		79	95
Iron		69	93
Lead		79	90
Mercury		91	98
Nickel		77	95
Zinc		92	98

Castro Valley Creek Sediment Quality

Another method to estimate necessary urban runoff controls is to compare the sediment quality in the urban stretch of the receiving water with an upstream stretch not affected by urban runoff. This is a reasonable method when long-term effects are important. Table 3-9 summarizes the sediment quality of Castro Valley Creek. The increases in sediment pollutant concentrations with urbanization for this creek were not as pronounced as observed in Coyote Creek (Pitt and Bozeman, 1980). This is because the Castro Valley Creek upstream watershed was much more heavily developed than the Coyote Creek upstream watershed. The concentration increases for the urban sediments observed in Castro Valley sediments were about 1/2 of the concentration increases observed for Coyote Creek.

Bottom sediment quality from Lake Merritt, an urban receiving lake in downtown Oakland, California, about 25 miles north of Castro Valley (Pitt & Bozeman, 1979) was also compared to Castro Valley sediments. Average Lake Merritt sediment concentrations for arsenic, total kjeldahl nitrogen, total phosphates and chemical oxygen demand were very similar to the sediment concentrations observed in the urban regions in Castro Valley and Coyote Creek. However, the lake sediments contained about 1,000 mg/kg of lead, about 10 times greater than the lead sediment concentrations observed in the urban area in Castro Valley Creek. The lake sediment zinc concentrations averaged more than 600 mg/kg, or about 4 times the Castro Valley Creek zinc sediment concentrations. Lake Merritt has a limited natural ability to remove polluted sediments and acts as a sink for settleable urban runoff pollutants, except for periodic dredging. Because the lead and zinc are associated with relatively denser urban runoff particulates, they can be expected to accumulate in this lake receiving water to a much greater extent than in the free-flowing creeks.

Table 3-9 also shows an average estimated urban runoff control necessary for the urban sediments to have the same strengths as the rural sediments. Lead reductions of about 70% and zinc reductions of about 35% may be necessary. However, the urban sediment chemical oxygen demand, total kjeldahl nitrogen and ortho-phosphate concentrations were all less than the corresponding concentrations in the rural sediments. This was surprising, considering the much increased urban runoff yields associated with these nutrients and organic constituents in the urban area as compared to the rural area. It can be assumed that the more soluble organics and nutrients are flushed through the urban streets more effectively because of increased creek flows, and do not have a change to accumulate in the creek sediments.

TABLE 3-9. STRENGTHS OF CASTRO VALLEY CREEK SEDIMENTS
(mg constituent/kg total solids)

Castro Valley Creek Sediments:	Lead	Zinc	COD	TKN	OPO_4
"Rural" Station:					
Above Seaview	40	88	23,000	1,000	10
Seaview Confluence	42	174	97,000	2,500	47
Seaview Gaging Station	43	96	6,300	600	<5
Urban Stations:					
Heyer St.	155	173	17,000	700	8
Berdina St.	120	176	13,000	600	5
Knox Gaging Station	143	170	15,000	800	13
Chabot Confluence	120	212	13,000	400	10
Estimated Runoff Control Necessary for Urban sediments to have the same strengths as the "rural" sediments	69%	35%	0%	0%	0%

SECTION 4

STREET CLEANER PERFORMANCE

Introduction

This section describes the street cleaning equipment used in the project, provides cost data specific to Alameda County street cleaning operations and details the effectiveness of the cleaners in removing the street surface contaminants.

The objectives of the street cleaning equipment performance tests in Castro Valley were to investigate various street cleaning practices under actual field conditions, including various street surface conditions, street surface particle loadings, traffic densities, parked cars, and climatic conditions, in order to determine the range of possible cleaning performance. This information is used with the information presented in Section 3, Receiving Water Measurements, to examine the potential of street cleaning programs to improve receiving water quality, which is discussed in Section 6.

Appendix B describes the field and laboratory procedures and the field instrumentation that was used to conduct these street cleaning equipment tests. Basically, the particulate sample was obtained from the street surfaces in the test basins immediately before and immediately after cleaning. The two observed loadings were then compared to obtain measures of street cleaning effectiveness. These samples were then divided into eight discrete particle sizes, weighed and then composited over selected time periods for each particle size and test area for chemical analyses. The resultant runoff pollutant loadings on the streets were then available for comparison. Again, these particulate loading values on the streets and the street cleaning effectiveness were used in conjunction with the observed runoff yields to determine the street cleaning program's ability to reduce runoff yields.

Typical Street Cleaning Equipment Descriptions

Mechanical street sweepers are designed to loosen dirt and debris from the street surface with a pick-up broom, transport it onto a moving conveyor, and deposit it temporarily in a storage hopper. Mechanical sweepers usually have a dust control system comprised of a spray bar which wets the street in front of the street sweeper. Mechanical street sweepers use a rotating gutter broom, typically made of steel wire, to remove the particles from the gutter area and throw them into the path of a large cylindrical pick-up broom which is usually made of plastic fibers. This large pick-up broom rotates and throws the material up onto a conveyor belt which deposits it into a hopper. Models with self-dumping hoppers are available with three and four wheels. Three wheel mechanical sweepers are generally more maneuverable, while four wheel sweepers can travel at higher road speeds when not cleaning.

Another type of mechanical street cleaner is the regenerative air street cleaner. Using air that is continuously being recycled through the unit, these cleaners are designed to blast the dirt and debris from the road surface and into a hopper using a blasting and vacuuming airflow. A portion of the air is then vented through the dust separation system. Regenerative air street cleaners also use water sprays for dust control.

The third common type of mechanical street cleaner is the vacuum assisted cleaner which has been used in Europe for many years and has become more popular in this country recently. These street cleaners use both a broom for loosening and moving the street dirt from the gutter into a main pick-up broom, typically of small diameter with steel wires. The pick-up broom then picks up the debris and throws them into a vacuum system, not a mechanical conveyor. All material picked up by the vacuum system is saturated with water on entry and passes into the vacuum chamber where the water-laden dust and dirt drop out of the airstream.

When the hopper of a street cleaner is filled, the material is either taken in the street cleaner to a storage or disposal site, or, as is a more common practice, simply dropped in a convenient place along the street cleaning route in an interim storage pile. The dirt and debris from these interim storage piles are later collected by truck crews, usually with a front end loader. Most of the street cleaners dump their hoppers from the bottom, but some models are available with hoppers that swing up and can be unloaded directly into a truck or container, thus eliminating the need for a separate pick-up crew, and decreasing the chances for storage pile losses.

The operating speed of most street cleaners falls in the range of four to eight miles per hour. However, when cleaning main arterial streets or freeways, slow operating speeds can be dangerous, so four-wheel street sweepers are usually used up to 15 mph in these cases.

Auxiliary engines or special power take-off transmissions provide variable rotation speeds to brooms and elevators independently of the forward speed of the street cleaning equipment. In addition, most new models are available with hydraulic controls which allow the street cleaner operator to make adjustments of the brooms and debris deflectors while in the cab and moving. These hydraulic controls, when available to a skilled operator, may substantially increase the effectiveness of the street cleaning equipment under variable loading and changing street and gutter conditions. Most of the street cleaning tests for this project were conducted using a modern mechanical four-wheel street cleaner. A special series of side-by-side tests, which are described in Section 5 of this report compared the mechanical street cleaner to a regenerative air street cleaner. Previous studies in the South San Francisco Bay Area (Pitt, 1979) examined the differences between four-wheel mechanical street cleaners and vacuum-assisted mechanical street cleaners.

Alameda County Street Cleaning Programs and Practices

Table 4-1 summarizes the street cleaning effort used by the Alameda County Public Works Department during the 1979-1980 fiscal year. Typically, the strip commercial land-use areas were cleaned once a week and the residential areas were cleaned once every six to eight weeks. All of the county unincorporated areas are cleaned by the County Road Department, and a total of 16,400 curb miles were cleaned during the 1970-1980 fiscal year. Three, four-wheel mechanical street cleaning devices are owned by the Public Works Department of Alameda County. Two of these were in operation in the "Bay Flats" service area where this demonstration project is located, and an additional street cleaner was used in the Livermore Valley service area.

TABLE 4-1 ALAMEDA COUNTY STREET CLEANING PROGRAM (1979-80).*

Land-Use	Cleaning Frequency
Strip Commercial	Once a week
Residential	Once every 6 to 8 weeks

Street Cleaner Type	Year Manufactured	Number of Units
4-Wheel Mechanical (Mobil 1TE3)	1973	1
	1977	1
	1979	1
		(3)**

* All unincorporated areas are cleaned by the County Road Department: 16,400 curb miles were cleaned during the 1979-1980 Fiscal Year.

** One of the street cleaners is located in the Livermore Valley Service area and the others are located in the "Bay Flats" service area.

Table 4-2 summarizes the equipment and operating conditions that were used during this project, and which are typically used by the Alameda County Road Department. The equipment tested was a four-wheel mechanical broom sweeper that had dual gasoline engines with hydraulic controls. Interim disposal sites were used in the service area with separate transfer of the debris to the landfill, as required. The speed during the cleaning program was about 5 to 8 mph and broom replacement and other maintenance was conducted on a scheduled basis. Because of the nature of this urban runoff monitoring project, these specific operating conditions were held constant during the study program and were not varied.

Important elements that could significantly change the cleaning effectiveness of the equipment, as compared to the standard procedures were not monitored. These differences would include different vehicle speeds, different rotation speeds and strikes of the main pick-up broom, and different broom materials. Some previous information, summarized by Pitt, Ugelo and Sartor (1974) show that a vehicle speed of about 4 mph may pick-up the most material per equipment pass. However, 25 to 50% less street miles would be cleaned in one day with this slower equipment speed, with probable resultant increases in unit removal costs.

Multiple passes of the same or different types of equipment on a single day with longer periods of time between street cleaning may change the cost-effectiveness of street cleaning. Again, monitoring these changes were beyond the scope of this project, but the project does indicate only little additional possible benefit for different application schemes. The idea of most street cleaning operations is to keep the street surface particulate loadings below a maximum value. This requires an evenly spaced street cleaning program, which would then minimize the accumulation period between street cleanings. If two passes were conducted on a single day every two weeks, instead of one pass every week, the streets would probably be slightly cleaner after the multiple pass. However, the loading on the streets before the multiple passes would be much greater than before the single pass, because the accumulation period between cleaning would be twice as long. Therefore, it is suggested that street cleaning operations be conducted in an even manner with respect to time. More importantly however, the street cleaning equipment should be used in those service areas with the dirtiest streets more frequently than in those areas with clean streets.

It costs about the same (less than a ten percent difference) for the street cleaning equipment to clean a mile of very clean streets as it does to clean a mile of moderately dirty streets. However, the same effort and money can remove much more material from the moderately dirty streets than from the very clean streets. As shown later in this section, using a piece of street cleaning equipment on a very clean street may actually increase the street surface loading in the cleaning path after street cleaning.

TABLE 4-2. STREET CLEANER OPERATING CHARACTERISTICS

- Make of Equipment: Mobil Athey
- Model: 2TE3, 4-wheel mechanical broom sweeper
- Year: 1980
- Engine Type: dual gasoline engines, with hydraulic controls
- Hopper capacity; 3½ yd^3
- Fuel efficiency: 50 miles per day and 21-22 gallons per day (both engines operating) = 2.3 mi./gal.
- Debris disposal practices: interim service area storage with separate transfer to land-fill as required.
- Speed during cleaning: 5 to 8 mph
- Type of gutter broom: steel
- Type of main pick-up broom: polyethylene
- Broom replacement intervals: main broom every 1500 miles, gutter broom every 200 miles
- Broom rotation speed: both brooms at 110 rpm
- Strike pressure of main pick-up broom: 4" pattern
- Maintenance schedule: daily, 2500 miles ("A" service) and 10,000 miles ("B" service);

  daily service: refuel and visual inspection

  2500 mile "A" service: oil change and lubrication

  10,000 mile "B" service: tuneup, oil change, wheels and brakes checked, general checkup

This is due to possible erosion of the street surface material (especially on streets in poorer condition) or by redistribution of material caused by equipment turbulence.

A survey of the street cleaning practices in all of the cities in Alameda County was undertaken by the Alameda County Flood Control District, as part of their original 208 work (Shawley, May, 1980). They found that countywide, about 130 miles of commercial areas are cleaned, from 6 to 350 times a year, with an average of about 165 times a year, or almost every other day. A total of about 70 miles of industrial curbs are cleaned from one to 100 times per year, with an average of about 40 times a year, or a little less than once per week. Almost 900 curb miles of residential streets are cleaned countywide, from 1 to 52 times a year, with an average of about 17 times, or about once every week and a half. Therefore, more than half of the total street cleaning effort countywide is used on very clean commercial streets, while less than 10% of the countywide street cleaning effort is expended on the much dirtier industrial areas. The residential areas account for about 40% of the annual street cleaning countywide effort.

The existing street cleaning programs would be much more cost-effective (on a dollar per pound removed basis) if more street cleaning effort was utilized in the industrial areas, and much less in the commercial areas. The residential areas are probably cleaned at an appropriate frequency. Cleaning streets more than about three times in one week is not as effective, but major improvement of the street surface loadings can be observed when changing from a monthly to a weekly street cleaning frequency.

About 28 pieces of mechanical street cleaning equipment is operated countywide, with an average age of two years. The average down-time for this equipment is about 15% but can range up to 40%. Twelve pieces of vacuum assisted street cleaning equipment also operate countywide, with an average age of three years, and also with an average of 15% down-time which ranges up to 50% in certain cases. The budgets for street cleaning remained about the same countywide from the 1977-78 to the 1978-79 fiscal years (about 1-1/2 million dollars identified) but individual cities had changes ranging from a reduction of 86% to an increase of about 16%. About 33% of the cities had parking restrictions during street cleaning for commercial areas, 17% had parking restrictions in industrial areas, and 18% had parking restrictions in residential areas. One to 10% of all of the streets countywide were under new construction. An additional 1 to 9% of the streets were new asphalt or concrete overlays, and up to 8% of the streets were newly slurry sealed. Therefore, over 70% of the street surfaces countywide are older than one year old.

Since the 1976-1977 fiscal year, the annual budgets for street cleaning have been reduced significantly. That fiscal year had an annual street cleaning budget of about 2.2 million dollars, while the 1978-79 budget was about 1.5 million dollars. There are indications that the fiscal year 1980-81 budget will also be much reduced. However, these estimated street cleaning costs are uncertain, because of the lack of complete accounting of street cleaning expenditures. It has been noted (Shawley, 1980) that rational decisions based upon changes of street cleaning effort are difficult when the complete costs are not actually known.

Street Cleaning Costs

An analysis was made of the Alameda County Road Department's street cleaning costs as part of this project. Table 4-3 shows this information for the 1979-1980 fiscal year. The major cost category was for labor, (street cleaning operators only) which made up about 40% of the total cost shown. The indirect labor costs, including administrative and support labor and employee benefits were about an additional 16%. Unfortunately, these labor costs only include the street cleaner operators and do not include the direct maintenance labor and the labor required to move the debris from the interim disposal areas to the final disposition areas. The next largest cost category was operation and maintenance supplies, which comprised 28% of the total, and included broom replacement, tires, fuel, oil, and repair supplies. The costs for disposing of the debris was about 11% of the total cost, while equipment depreciation was about 5%. The indirect labor costs do not include the costs for the buildings and the grounds, overhead for the street cleaner equipment storage and maintenance. Therefore the total unit costs of ten dollars per curb mile cleaned is significantly lower than what the actual costs would be for a larger operation, an expanding operation or for a basic operation just beginning.

Because the street cleaner fleet for the Alameda County Road Department comprises only a small portion of their other large equipment fleet which is significantly larger, costs associated with maintaining the few pieces of street cleaning equipment were not included. However, for a larger street cleaner operation, these would be important costs and based upon information for the City of San Jose (Pitt, 1979) the extra maintenance and debris transfer labor can be about three dollars per curb mile cleaned and the warehouse and grounds costs for equipment storage and maintenance can be about two dollars per curb mile cleaned. Therefore, the actual total cost is

TABLE 4-3. ALAMEDA COUNTY ANNUAL STREET CLEANING COSTS (1979-1980 FISCAL YEAR).

Category	Total Costs ($)	Unit Cost(6) ($ per Curb-Mile)	Percentage of Total Cost (%)
Operation and Maintenance Supplies (1)	$ 46,600	$ 2.84	28%
Disposal of Debris (2)	17,900	1.09	11
Equipment Depreciation	8,600	0.52	5
Total Labor			
direct(3)	69,100	4.21) 5.86	40) 56
indirect(4)	27,000	1.65)	16)
TOTAL COSTS(5)	$169,000	$10.30 (7)	100%

(1) Includes broom replacement, tires, fuel, oil and repair supplies.

(2) Based on 420 loads disposed at landfill at 5 yd^3 each = 2100 yd^3.

(3) Only includes street cleaner operators at 5385 hours (673 days) and 0.33 hours per curb-mile cleaned. Does not include maintenance labor and labor required to move debris from interim disposal areas to final disposal areas.

(4) Includes direct administrative and support labor costs, plus indirect employee benefit costs. Does not include buildings and grounds overhead for street cleaner equipment storage and maintenance.

(5) Partial costs only due to missing items noted above.

(6) Based on 16,400 curb-miles cleaned during this period.

(7) Based on San Jose costs (Pitt, 1979), the extra maintenance and debris transfer labor is estimated to be about $3.00/curb-mile cleaned and the warehouse cost is estimated to be about $2.00/curb-mile. Therefore, the actual total cost is estimated to be $15.00/curb-mile cleaned.

estimated to be closer to fifteen dollars per curb mile cleaned for Alameda County, considering these shared service costs that are currently being totally supported by the majority of the heavy equipment fleet. As a comparison, the expected 1979-1980 costs for the previously studied San Jose area would be about eighteen dollars per curb mile cleaned. These cost values are difficult to compare to costs reported elsewhere because of the unknown accounting procedures and the poorly documented cost elements.

Some limited street cleaning cost information nationwide is available from a 1973 survey conducted by the American Public Works Association (APWA, 1975). This survey involved extensive questionnaires that were sent to about 400 cities nationwide. These costs (increased for 1979 and 1980 cost conditions, as based on the Engineering News Record Index) showed that typical city expenditure was about two dollars per person per year, or about one percent of the typical city budget. A large portion of the street cleaning budget went for equipment maintenance, although the exact percentage was not available during this survey. The total maintenance cost was about three dollars per curb mile cleaned, with the greatest portion spent for brooms, brushes and other major repairs. Cities found that brushes were the component most subject to wear, followed by conveyor and elevator drives, tires, the hydraulic system and finally transmission. The average life of a synthetic main pick-up broom was reported to be a little more than one thousand curb miles cleaned, ranging from about 100 to 2500 miles.

Castro Valley Street Cleaning Effectiveness Tests

Several street cleaning frequencies were evaluated in different test areas during the first project year, while the second project year used the same street cleaning program in all three of the test areas. The street cleaning schedule that was used is presented in Table 4-4. During the first year, the study basin was divided into three areas and the time frame into five segments, and different street cleaning programs were conducted in each of the areas. An initial street cleaning activity was conducted during the first project week and was not monitored. This extensive cleaning effort resulted in quite clean streets and a time frame from which to start the study. In addition, leaf removal activities were conducted during one-week of both years to remove most of the leaf debris from the streets. The street loadings for each day of these leaf removal efforts were also measured. The street cleaning programs that were studied varied from one to five passes every week. Additionally, six to fifteen weeks passed with no street cleaning. During the second project year, daily street cleaning was conducted for one month over the complete basin, followed by two months of no street cleaning. This enabled the streets to become as dirty as they were likely to become during the first month and because of the differences between the deposition and accumulation rates they remained at about that same level during the second month. This street cleaning schedule permitted street surface loading condtiions to vary over a wide range. This information was used to evaluate the street surface particulate accumulation rates and the street cleaner performance.

TABLE 4-4. STREET CLEANING SCHEDULE(1)

5-Day Work Weeks		Upper Urban Area	Middle Urban Area	Lower Urban Area
11/20	11/24/78	1(2)	1(2)	1(2)
11/27	12/1	0	0	0
12/4	12/8	4L(3)	4L(3)	4L(3)
12/11	12/15	0	0	0
12/18	12/22	0	0	0
12/25	12/29	0	0	0
1/1	1/5/79	0	0	0
1/8	1/12	0	0	0
1/5	1/19	0	1	0
1/22	1/26	0	1	0
1/29	2/2	0	1	0
2/5	2/9	0	1	0
2/12	2/16	0	0	0
2/19	2/23	0	0	1
2/26	3/2	3	0	0
3/5	3/9	1	0	0
3/12	3/16	0	3	0
3/19	3/23	0	0	1
3/26	3/30	0	0	1
4/2	4/6	0	0	1
4/9	4/13	0	0	1
4/16	4/20	0	0	1
4/23	4/27	1	0	0
4/30	5/4	1	0	0
5/2	5/11	1	0	0
5/14	5/18	0	0	5
5/21	5/25	1	0	0
5/28	6/1	1	0	0
6/4	6/8	0	0	0
6/11	6/15 (4)	1	1	1
10/30	11/2	1(3)	1(3)	1(3)
11/5	11/9	1	1	1
11/12	11/16	1	1	1
11/19	11/23	1	1	1
11/26	11/30	1	1	1
2/4	2/8/80	4	4	4
2/11	2/15	2	2	2
2/18	2/22	0	0	0
2/25	2/29	2	2	2
3/3	3/7	0	0	0
3/10	3/14	2	2	2

(1) Number of street cleaning tests per week are shown - all performed with standard, mechanical sweeper

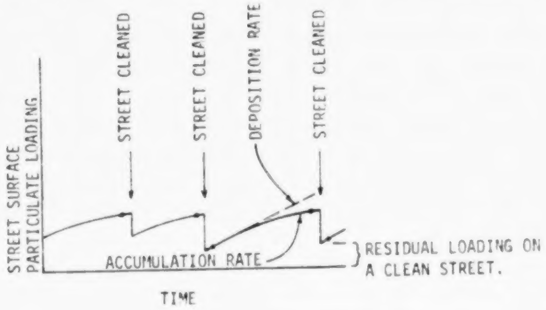
(2) Not monitored; starting date

(3) Leaf removal tests

(4) Second year program - combined areas (one area swept)

Street cleaner equipment performance is very sensitive to operator skill and equipment maintenance. The previous sub-sections described the equipment maintenance and operations that were followed during the course of the study period. The operators and maintenance personnel used during these tests were supplied by the Road Department of Alameda County. They were all well-trained, skilled and operated the test equipment in an optimum and recommended manner.

Long-term and frequent street surface sampling in the test areas made it possible to directly measure the accumulation rates of street surface contaminants. Street surface samples were collected within a few hours before and after the street cleaning by the procedures described in Appendix B. The idealized loading pattern resulting from sampling at these intervals, a sawtooth pattern depicting the deposition and removal of street surface particulates, is illustrated in Figure 4-1. The accumulation rates for the various contaminants were then calculated, based on the angle of the slope between adjacent sampling periods, and were described previously.



SAWTOOTH PATTERN ASSOCIATED WITH
DEPOSITION AND REMOVAL OF PARTICULATES

FIGURE 4-1.

The data collected in these test areas were used to identify the range of performance that can be expected from the available street cleaning equipment. Differences in removal values, expressed on a "pounds per curb-mile removed" basis, instead of percentage removals (percent of the initial loadings removed) and the initial and residual street surface loading values are all used as meaningful measures of equipment performance. The street cleaning program may have a very low percentage removal value, but a high total amount removed if the initial loading value is high.

Figures 4-2 and 4-3 present the productivity relationships between initial total solids loading values and residual loading values. Quite reasonable linear relationships were observed for both years and for all three test areas. As expected, the upper study area with the lowest initial loading values had the smallest percent removals. In many cases, observed residual loading values were actually less than the initial loading values before street cleaning for the upper study area. The differences in test area performance was mostly a function of the initial loading values on the streets, which were probably due to the street's topography and the area's general socio-economic conditions. As noted earlier, the specific street surface conditions in all three areas were quite similar. Figure 4-3, for the second year, shows that for the very cleanest street surface loading conditions (associated with several street cleaning passes in one week) the residual loadings were also significantly greater than the initial loadings. However, for conditions when the streets were the dirtiest (initial loadings of about 1,000 or more pounds per curb mile) the cleaning effectiveness was about 40%. Therefore, the range of percentage removal values varies appreciably but the residual loading values could not be lower than about 200 pounds per curb mile.

Figures 4-4 and 4-5 present initial and residual street surface loading values for total solids as a function of the cleaning effort for the three test areas in the first year and for the total area in the second year. In addition, Table 4-5 summarizes the initial street surface loading conditions for various cleaning programs for the compelte study area. These figures and tables show that significant differences in residual and initial street surface loading values can be had by increasing the street cleaning program up to about one pass per week from monthly, or less frequent cleaning. After about two to three passes per week, there is very little improvement in either initial or residual street surface loadings. Under these cases, the streets are about as clean as they are likely to get by street cleaning operations and any more frequent street cleaning would be wasted effort.

Figure 4-6 is a rough estimate of the total street surface particulates removed per curb mile per year, as a function of the cleaning frequency. This is based upon the first year information and shows a sharp decrease in yearly removals for frequent street cleaning. These last three figures demonstrate the ineffectiveness of frequent street cleaning in areas that are clean. it is much more cost-effective to reduce the street cleaning effort in those areas having frequent street cleaning with clean streets and increasing the street cleaning effort in those areas that currently have very little street cleaning with appreciably dirtier streets.

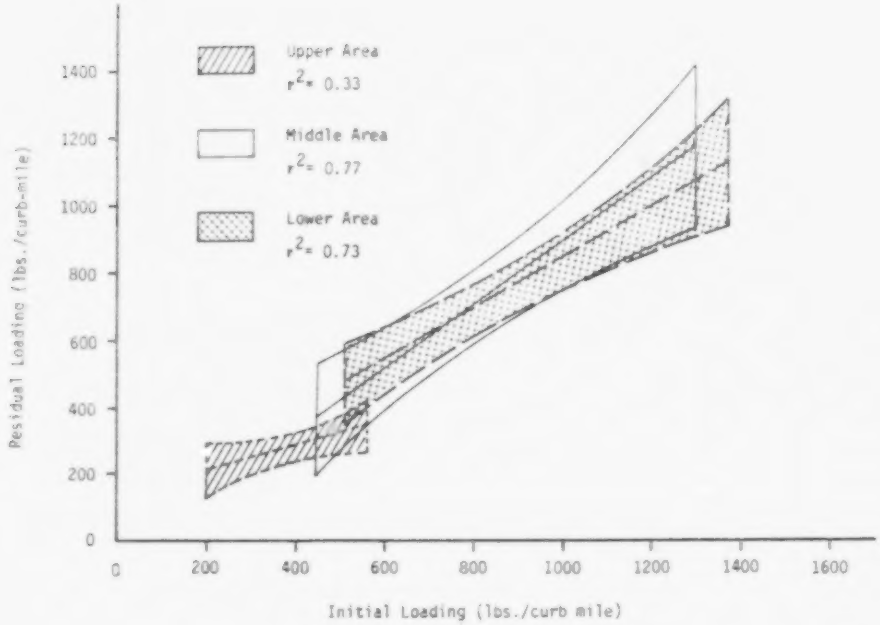


FIGURE 4-2. FIRST YEAR STREET CLEANER PRODUCTIVITY
(95% confidence interval shown)
TOTAL SOLIDS

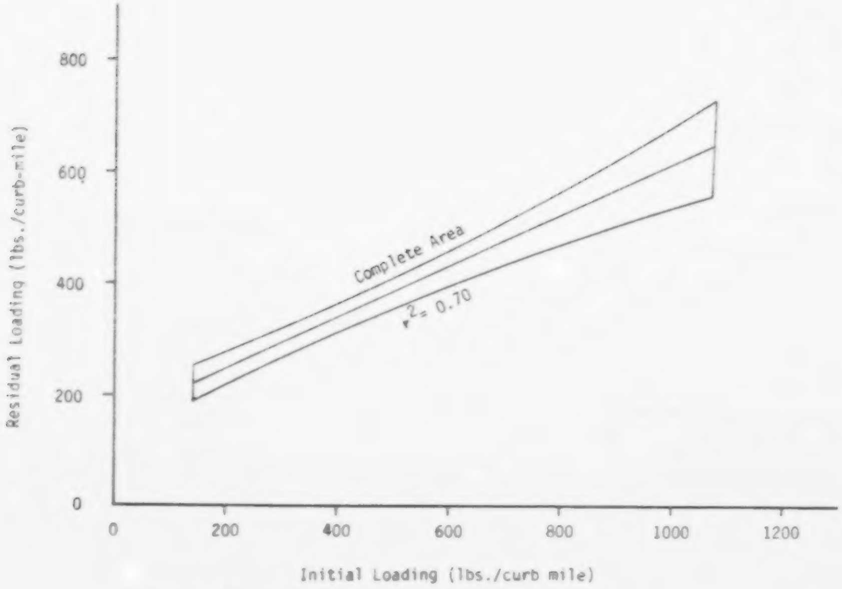


FIGURE 4-3. SECOND YEAR STREET CLEANER PRODUCTIVITY
(95% confidence intervals shown)
TOTAL SOLIDS

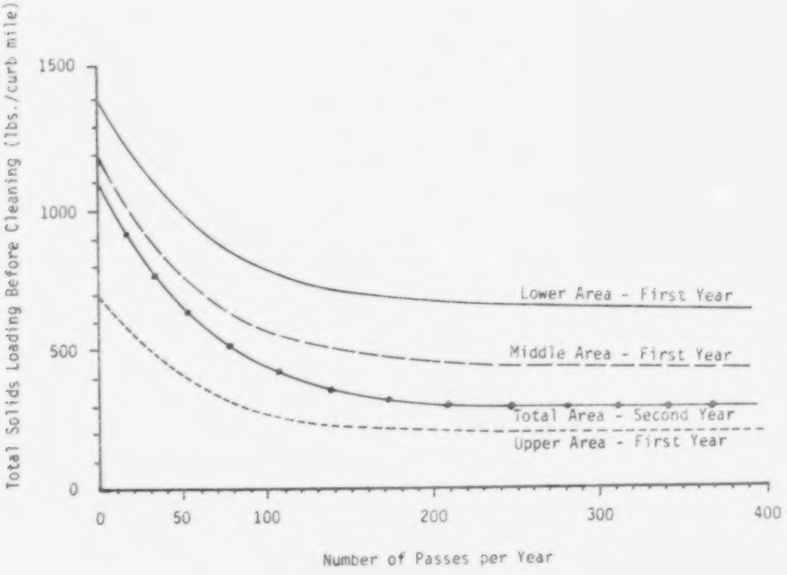


FIGURE 4-4. INITIAL TOTAL SOLIDS STREET LOADING AS A FUNCTION OF CLEANING EFFORT

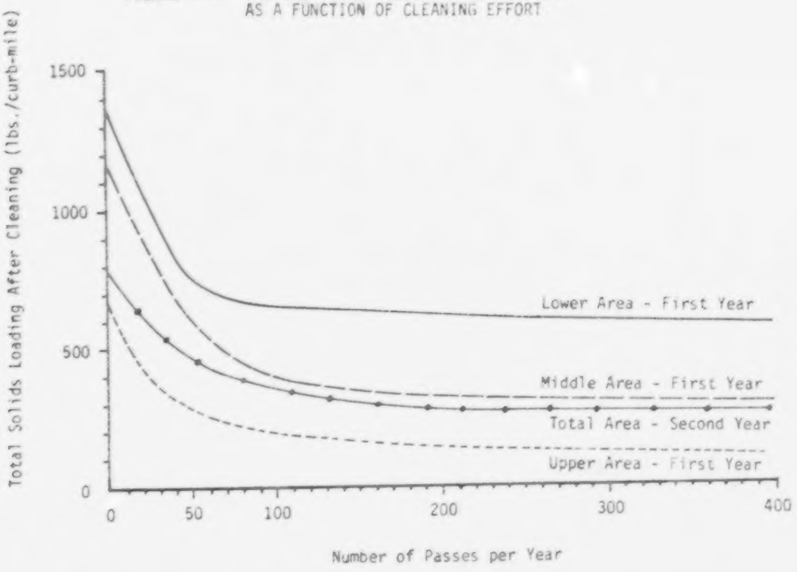


FIGURE 4-5. RESIDUAL TOTAL SOLIDS STREET LOADING AS A FUNCTION OF CLEANING EFFORT

TABLE 4-5. OBTAINABLE INITIAL STREET SURFACE LOADINGS FOR VARIOUS CLEANING PROGRAMS (lbs/curb-mile) (complete study area)

Number of passes per: Year	Week	Total Solids	Lead	Zinc	Arsenic	Copper	Chromium	COD	Phos.	$O\text{-}PO_4$	TKN
0	0	1100	1.7	0.28	0.015	0.088	0.20	100	0.52	0.033	1.7
4	1/13	1050	1.6	0.26	0.015	0.084	0.19	96	0.49	0.032	1.6
12	1/4	950	1.4	0.24	0.013	0.076	0.17	86	0.45	0.029	1.4
24	1/2	850	1.3	0.21	0.012	0.068	0.15	77	0.40	0.026	1.3
52	1	650	0.98	0.16	0.0091	0.052	0.12	59	0.31	0.020	0.98
104	1	450	0.68	0.11	0.0063	0.036	0.081	41	0.21	0.014	0.68
156	3	350	0.53	0.088	0.0049	0.028	0.063	32	0.16	0.011	0.53
208	4	300	0.45	0.075	0.0042	0.024	0.054	27	0.14	0.0090	0.45
260	5	300	0.45	0.075	0.0042	0.024	0.054	27	0.14	0.0090	0.45
365	7	300	0.45	0.075	0.0042	0.024	0.054	17	0.14	0.0090	0.45

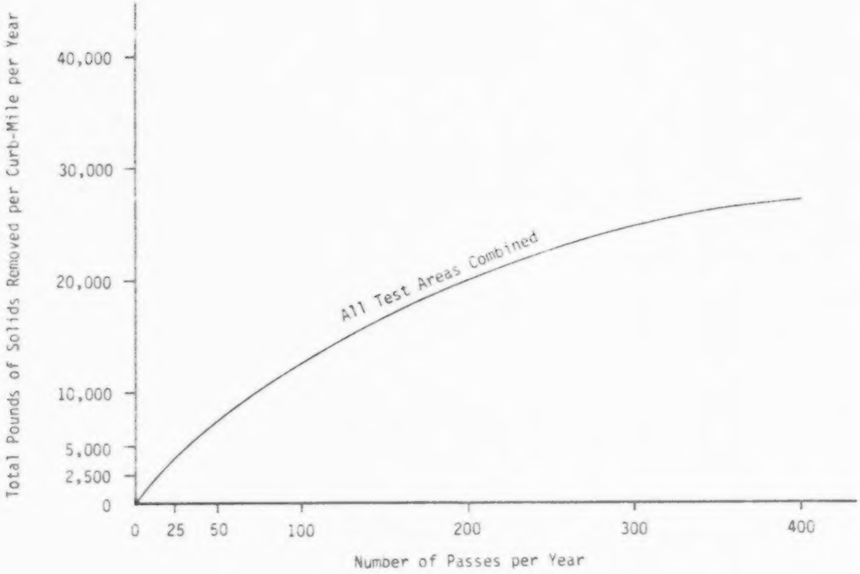


FIGURE 4-6. STREET DIRT REMOVED AS A FUNCTION OF STREET CLEANING EFFORT

SECTION 5

COMPARISON OF MECHANICAL AND REGENERATIVE-AIR STREET CLEANING EQUIPMENT PERFORMANCE

Introduction

This section describes the tests conducted to evaluate the performance differences between two common types of street cleaning equipment. These comparative tests provided information directly relevant to the projects first two objectives.

A series of special tests were designed and carried out as part of the San Francisco Bay Area NURP to examine the differences in performance of regenerative-air and mechanical street cleaning equipment. Very little information is available in the literature comparing different types of street cleaning equipment under similar conditions. Previous studies that have investigated equipment performance differences were limited by equipment selection and conflicting objectives of the projects. Pitt (1979) compared the performance of standard mechanical, state of the art mechanical and vacuum assisted mechanical street cleaning equipment under typical conditions in San Jose, CA. He found very little difference in performance of these three types of equipment. The study, however, did not compare the equipment under identical circumstances or within a short time period.

The conclusions were that differences in test area conditions and street cleaning intervals were much more important in removing street surface contaminants than the selection of equipment type. Other sources of information pertaining to differences in performance of street cleaning equipment were either based on tests conducted in different cities throughout the United States with different pieces of equipment (Sartor and Boyd, 1972) or were based on idealized strip test conditions conducted over several years with equipment that is no longer used (Clark and Coppin, 1963, 1964 and 1968; Lee, Sartor and Van Horn, 1959). These previous studies did show some possible performance differences for the equipment types studied, but as previously mentioned, these results cannot be considered applicable with the equipment types currently available or under tyical road conditions. Therefore, a simple test series was carried out as part of the Castro Valley Demonstration Project to examine the differences of two major types of street cleaning equipment currently available.

Description of Study Area and Testing Procedures

A series of test locations were selected in the area northwest of the Castro Valley study area. These test areas are made up of various street lengths corresponding to the conditions encountered in the main study area. Table 5-1 presents some general information pertaining to these test areas. These test areas are shown in Figure 5-1. There were two lower, middle and upper test areas used in this study. They ranged from 0.5 to 1.3 curb-miles each. During all of the tests, few leaves were present on the streets and the lower test area had more parked cars. The lower test areas were predominantly flat, while the middle areas were from flat to moderate in slope and the upper areas were moderate to steep in slope. The program involved testing one lower, one middle and one upper test area each day.

The mechanical street cleaner (Mech.) (a Mobil, model 2TE3) operated on one side of the street while the regenerative-air (RA) street cleaner (a Tymco, model 600) operated on the other side of the street. Each side was cleaned about every 3 or 4 days during the first half of December, 1979. The equipment rotated to the other side of the street on adjacent testing days. This enabled minor differences of the two sides of the streets to be cancelled out. The testing procedures used were similar to those used in the main study area. A "before", or initial sample, was collected from each side of the street in each test area before the equipment was operated. An "after", or residual street cleaning sample, was also collected within a short period of time after the streets were cleaned. The samples were then individually weighed, dried, re-weighed and divided into eight separate particle size ranges. No chemical analyses of these samples were made, but the representative chemical strengths observed for the three similar test areas in the main Castro Valley study area were used for data analyses. The following subsections present the basic data obtained during these tests, the accumulation rates and pollutant strengths that were used along with the productivity functions and particle size effects of the different types of street cleaning equipment tested.

TABLE 5-1. MECHANICAL AND REGENERATIVE AIR STREET CLEANING STUDY AREA DESCRIPTIONS

	Curb-Miles (1-Side of Street Only)	Leaves	Parked Cars (Cars/Mile	Street Conditions	Topography
Lower Areas					
I	0.9	Few	17	Good	Flat
II	0.5	Few	34	Good	Flat
Middle Areas					
I	1.2	Few	15	Good	Flat/Mod.
II	0.8	Few	21	Good	Flat/Mod.
Upper Areas					
I	1.1	Few	15	Good	Mod./Steep
II	1.3	Few	7	Good	Mod./Steep

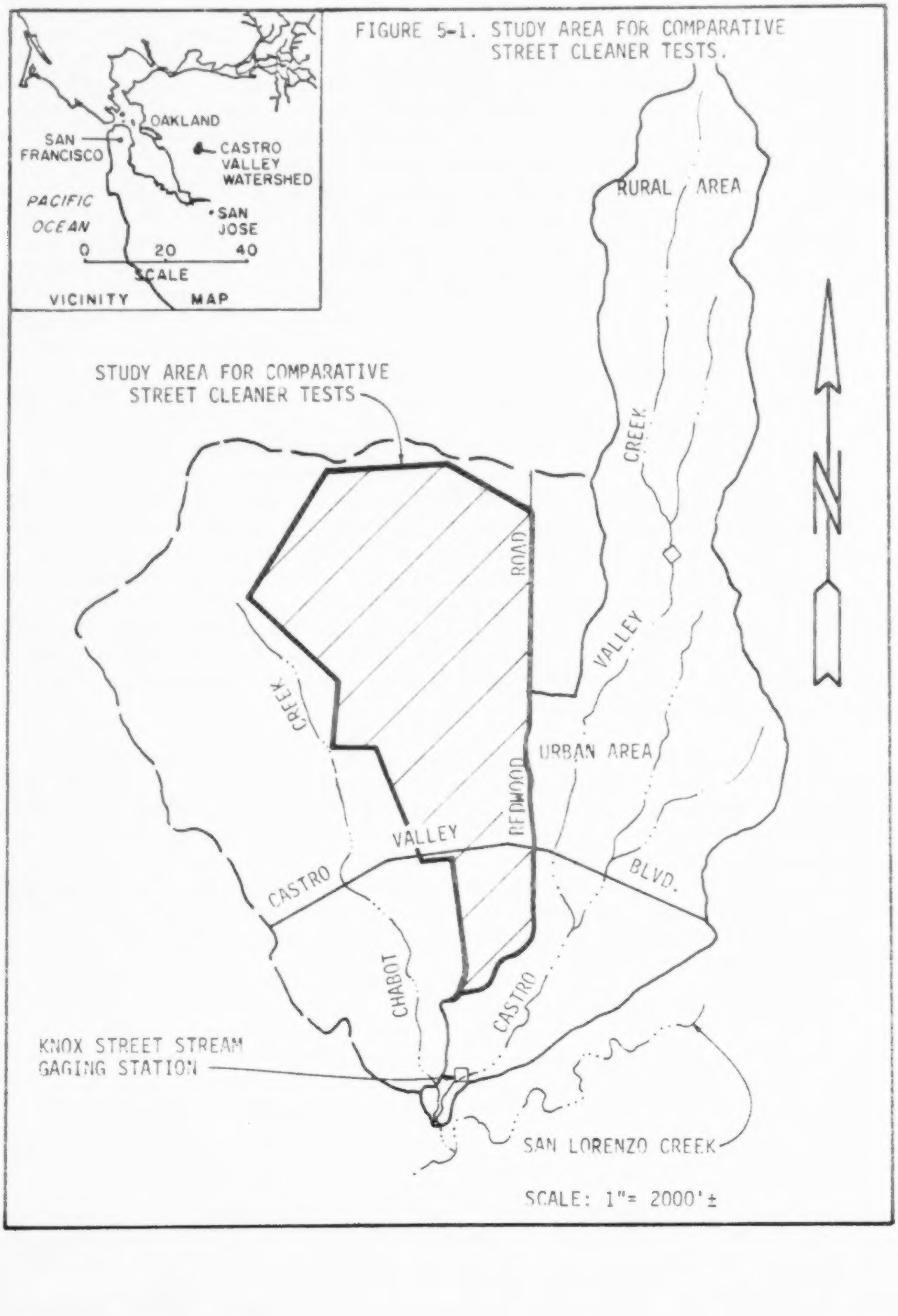


FIGURE 5-1. STUDY AREA FOR COMPARATIVE STREET CLEANER TESTS.

OAKLAND
SAN FRANCISCO
CASTRO VALLEY WATERSHED
PACIFIC OCEAN
SAN JOSE
0
20
40
SCALE
VICINITY MAP
RURAL AREA
STUDY AREA FOR COMPARATIVE STREET CLEANER TESTS
CREEK
VALLEY
ROAD
CREEK
URBAN AREA
REDWOOD
VALLEY
CASTRO
BLVD.
CHABOT
CASTRO
KNOX STREET STREAM GAGING STATION
SAN LORENZO CREEK
SCALE: 1"= 2000'±

Basic Data

Twenty-four street cleaning performance tests were conducted for each of the two types of street cleaning equipment. Eight were conducted in the lower area, 9 were conducted in the middle area and 7 were conducted in the upper area. Several additional tests were conducted, but were eliminated from analyses because of sampling difficulties or rain interference. Appendix F-1 thru F-3 presents the basic data for each of these 48 street cleaning tests. These Appendix tables present the date of the test, the days since the area was last cleaned, the initial street dirt loading, the residual street dirt loadings and the quantity of street dirt removed for that street cleaner test. Also shown is the parked car density observed during the test and the percentage street dirt removed. Because the tests were conducted in the winter and over a short period of time, the maximum period of accumulation (time since the last street cleaning or rain) was 10 days. The associated maximum street dirt loading observed was slightly less than 900 pounds per curb-mile. Based on the first year Castro Valley street cleaning tests, one could expect initial street surface loading values of about 1,000 to 1,500 pounds per curb-mile with accumulation periods of about 20 to 30 days. All of these tests were, therefore, conducted under very to moderately clean street surface conditions. The percentage removal values observed when examining this basic data are quite a bit higher than the values obtained from the tests conducted in the larger Castro Valley study area. This is most likely due to the differences in size between the two study areas. The small test areas were selected carefully in order to eliminate areas of unusually dirty and uncleanable locations (such as very poor gutter conditions or local erosion problems), while the larger study area has numerable locations that could not be cleaned adequately or had unusually high accumulation rates.

The percentage removal values for each individual test day for the regenerative-air street cleaning equipment are greater than for the mechanical street cleaning equipment. This was mostly due to the fact that the initial loading conditions before the regenerative-air street cleaning tests were typically greater than for the mechanical street cleaning test. However, the amount removed as a function of the initial loading value is a much more important street cleaning performance indicator than the percentage removal values. Table 5-2 presents the calculated composite pollutant strengths for the three comparison test areas.

TABLE 5-2. COMPOSITE POLLUTANT STRENGTH FOR STUDY AREAS

Pollutant	Strength (mg pollutant/kg total solids)		
	Lower Area	Middle Area	Upper Area
Litter	54,100	64,300	100,000
COD	86,400	86,500	85,500
TKN	665	640	620
OPO_4	5.2	3.9	5.3
Pb	2,200	2,290	1,280
Zn	416	270	206
Cu	238	229	229

Productivity Functions

Productivity functions were established by simply relating the total amount of street dirt particulates removed, to the initial particulate loadings, all expressed in pounds per curb-mile. Figure 5-2 presents the productivity relationship for all of the particle sizes combined, and over a common street surface loading range of about 100 to 900 pounds per curb-mile. The regenerative-air street cleaning equipment operated under typically dirtier street conditions and the figures are therefore expanded to represent all of the observed values.

The percentage removals obtained by the regenerative-air street cleaner at the lower initial particulate loading values are substantially greater than for the mechanical street cleaner. Therefore, under very clean street surface conditions, the regenerative-air street cleaning equipment can be considered more productive than the mechanical street cleaner. Under more typical (dirtier) loading conditions, however, the percentage difference between the two types of street cleaning equipment diminishes to insignificant levels, when the observed data scatter is considered. This implies that regenerative-air street cleaning equipment may be more effective in cleaning those areas that are cleaned very frequently and have very clean street surfaces.

Table 5-3 summarizes the percentage removal rates for the different particle sizes by the street cleaning equipment and under typical loading conditions for the three test areas. The minimum and maximum 99.5% confidence limit values are shown in addition to the average values. The regenerative-air street cleaning equipment is shown to remove the finer street dirt material (less than 2,000 microns) better than the mechanical street cleaning equipment. This difference can be as much as 15%. However, for the coarser material (greater than 2,000 microns) the mechanical street cleaner is shown to perform better than the regenerative-air street cleaner by 20 to 30%. Again, as the street dirt loading values increase, the differences in "percentage performance" decrease.

Appendix Figures F-1 thru F-8 compare the productivity curves for each particle size, while Figure F-9 shows how the street cleaning equipment redistributes the particle size upon cleaning. The median particle size for the mechanical equipment 'after loading' was about the same as the initial loading particle size (about 350u) while the RA 'after loading' median particle size was much larger (about 700u).

The different performance capabilities of the equipment for the different particle sizes can be expected to produce different removal results for the various pollutants. Tables 5-4 and 5-5 summarize the removal values on a percentage and on a pounds removed per pass basis respectively, for selected pollutants for each equipment type in each of the three test areas. The percentage removal values shown in Table 5-4 show that that the differences in performance for total solids is 8% or less, with the regenerative-air equipment being most productive. The greatest difference is associated with the cleanest (lower) area. Litter removal (litter being defined as material greater than 0.25 inches) is much better removed by the mechanical street cleaning equipment. This difference is shown to be 15% or less. The removals of the other pollutants shown are all better by the regenerative-air equipment. The differences observed for the various chemical parameters are equal to, or greater than, the differences observed for total solids.

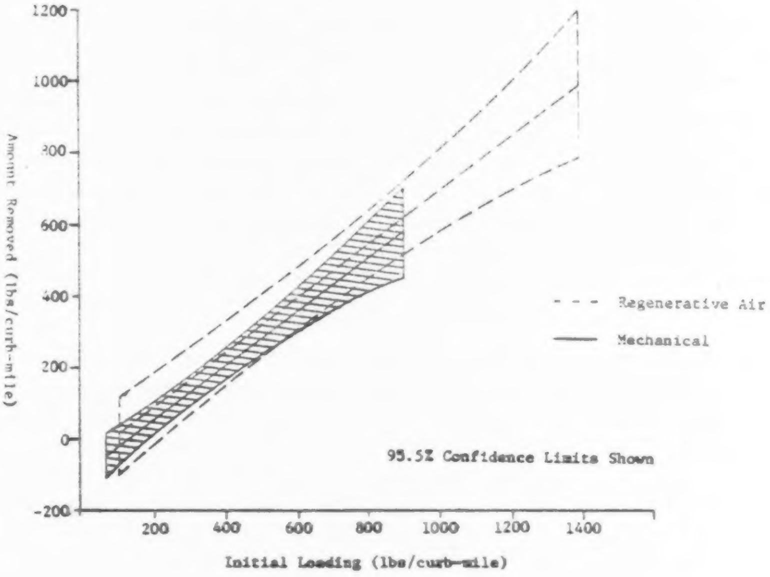


FIGURE 5-2. STREET CLEANING PRODUCTIVITY
TOTAL SOLIDS (all particle sizes combined)

TABLE 5-3. PERCENTAGE REMOVAL RATES FOR DIFFERENT PARTICLE SIZES AND STREET CLEANING EQUIPMENT

Particle Size (M)	Initial Particulate Loading (lbs/curb-mi.)	Removal Rate (percent) Mechanical Street Cleaner			Removal Rate (percent) Regenerative Air Street Cleaner		
		Min.	Ave.	Max.	Min.	Ave.	Max.
<45	38[1]	49	61	71	62	74	85
	30[2]	47	60	69	60	73	82
	11[3]	18	36	55	18	55	77
45-106	127	61	69	76	65	75	83
	87	55	63	69	60	69	78
	47	36	47	56	38	57	74
106-250	170	52	62	72	65	72	82
	139	51	60	71	63	72	81
	68	34	47	56	41	59	75
250-600	195	42	61	78	61	73	86
	173	42	60	76	60	71	85
	82	26	45	65	37	60	83
600-850	58	31	57	97	57	72	83
	53	36	57	83	72	69	85
	29	26	52	62	41	66	88
850-2000	129	49	62	80	53	67	80
	99	48	62	74	52	65	79
	67	46	57	68	46	60	79
2000-6370	87	63	77	89	22	46	71
	74	62	76	72	23	47	72
	56	59	71	84	21	50	79
>6370	46	52	71	90	29	57	83
	45	53	71	89	30	56	82
	40	52	70	88	32	57	81
TOTAL	850	50	64	76	56	69	82
	700	51	62	74	55	68	81
	400	41	53	65	40	61	82

1. Lower study area typical loading
2. Middle study area typical loading
3. Upper study area typical loading

TABLE 5-4. PERCENTAGE REMOVALS FOR SELECTED POLLUTANTS BY EQUIPMENT TYPE AND STUDY AREA[1]

Study Area	Equipment Type *	Total Solids	Litter	COD	TKN	OPO_4	Pb	Zn	Cu
Lower	Mech.	64	71	64	63	64	63	66	64
	R.A.	69	57	71	72	70	74	69	70
Middle	Mech.	62	71	62	62	63	60	61	63
	R.A.	68	56	68	69	67	72	71	69
Upper	Mech.	53	70	47	50	52	54	52	55
	R.A.	61	57	59	60	58	58	60	57

1. With typical initial loading conditions for study area: 850 lbs. total solids/curb-mile for lower area, 700 lbs. total solids/curb-mile for middle area and 400 lbs. total solids/curb-mile for upper area.

Table 5-5. POUNDS REMOVED PER PASS FOR SELECTED POLLUTANTS BY EQUIPMENT TYPE AND STUDY AREA[1]

Study Area	Equipment Type *	Total Solids	Litter	COD	TKN	OPO_4	Pb	Zn	Cu
Lower	Mech.	544	33	47	0.36	0.0028	1.2	0.23	0.13
	R.A.	587	26	52	0.41	0.0031	1.4	0.24	0.14
Middle	Mech.	434	32	38	0.28	0.0017	0.96	0.12	0.10
	R.A.	476	25	41	0.31	0.0018	1.2	0.14	0.11
Upper	Mech.	212	28	18	0.13	0.0011	0.24	0.041	0.048
	R.A.	244	23	20	0.15	0.0012	0.30	0.049	0.053

* Mech. = mechanical brush
R.A. = regenerative air

Table 5-5, however, presents the differences in equipment performance as a function of the total amounts of pollutants removed per pass. In this case, it is seen that the differences in the absolute values of pollutant removals are quite small for the two types of equipment. This difference is typically much less than the scatter of the observed and calculated data.

In conclusion, it can be seen that the regenerative-air street cleaning equipment may be most effective in servicing areas having low street surface particulate and litter loadings. The regenerative-air equipment type diminishes significantly when the initial street surface loading conditions are more typical, or are quite dirty. The mechanical street cleaning equipment may be best in those service areas having very heavy litter loadings.

SECTION 6

CONTROL OF URBAN RUNOFF

Introduction

This section summarizes the costs, effectivenesses, and magnitudes of potential uses of various urban runoff control measures. Street cleaning, of course, is emphasized as it was the control directly extended for this project. However, selected literature information is presented for other potential control measures for which data is available.

Controls Most Suitable for Various Source Areas and Pollutants

After the urban runoff problems (which pollutants, when, where and how much) and the source areas for these problem pollutants are identified, an appropriate urban runoff control program can be designed. Obviously, street cleaning can only be applied to those impervious areas that street cleaning equipment can get to. Inlets and storm sewerage system maintenance can only affect the material that accumulates in them. Treatment at the outfall, however, is capable of affecting pollutants originating from all of the sources.

The relative contributions and yields from each of these sources must be considered in determining the best combination of control measures. Table 6-1 shows the suitability of these various control measures for controlling the different urban runoff pollutants. This considers the relative source area strength, approximate control measure effectiveness and source area yields to the outfall. No single control measure is suitable for handling a broad range of pollutants. However, urban runoff treatment can be marginally too highly effective for treating many of them. However, even if a potential problem is confined to a single urban runoff pollutant, a combination of control measures will most likely be needed.

Necessary controls for potential urban runoff problem pollutants may need to be 90% or more effective. However, very few of these control measures are capable of affecting any of the constituents to that extent in the runoff. The most appropriate control measure combination can be selected knowing the potential removals and unit costs for each candidate. Not considering other urban runoff control objectives, or partial control of the other pollutants, one could simply start with the least costly unit control measure until the desired removal is obtained. If only a small quantity must be removed (not likely the case) the least expensive control option may be sufficient. However, if greater quantities must be controlled, then a combination of control measures will most likely be needed. The selected mixture of control measures could vary, depending on the constituents of concern and the total control needed.

TABLE 6-1. SUITABILITY OF CONTROL MEASURES FOR CONTROLLING COMMON URBAN RUNOFF POLLUTANTS

	Common Urban Runoff Pollutants								
Control Measures	Sediment	Oxygen Demanding Matter	Nutrients	Salts	Bacteria	Heavy Metals	Pesticides/ Herbicides	Oils and Grease	Floating Matter
Street Cleaning (with streets in good repair)	M*	L	L	M	L/M	H		M	M
Leaf Removal (seasonal use)		L/M	L/M		L	L	L	L	H
Control Grass Types	L	L	L				L/M		L/M
Repair Streets	L/M					L		L	L
Control Fertilizer, Pesticides, etc.			H				H		
Control Use of Vacant Land	L/M		L/M		L/M				
Control Litter		L	L		L/M			L/M	M
Control Dog Litter		L	M		M/H				L
Eliminate Cross Connections with Sanitary Sewers		L/M	L/M		M/H				
Clean Catchbasins	L					L/M		L	
Clean Storm Sewers and Drainage Channels	L/M					L/M		L	
Prevent Roof Drainage from Directly Entering Storm Sewer			L			L		L	
Direct Runoff Away from Contaminated Areas	M								
Retain Runoff from Contaminated Areas	M								
Regrade Disturbed Areas	M		L						
Control Erosion at Construction Sites	M							L/M	
Store and Treat Runoff	H	M/H	M	L	H	L/M	L	M	H

*L - Low suitability
L/M - Low-medium suitability
M - Medium suitability
M/H - Medium-high suitability

Source: Pitt, 1979.

Effectiveness of Street Cleaning Operations in Improving Receiving Water

Specific urban runoff yields can be related to street surface initial loading values for each constituent. For those storms with small urban runoff flows, almost all of the urban runoff yields can be accounted for by the initial street surface loadings. In many cases with the smallest storms, the initial street surface loading values were much larger than the total urban runoff yield, signifying that either not all of the initial street surface loadings were washed off during the storm, or that most of the material that was removed from the street surface accumulated in the sewerage system before final discharge on subsequent storms. Similarly, under storm conditions having very large urban runoff flows, the initial street surface loadings (the maximum contribution from the street surfaces to the urban runoff) were much smaller than the total urban runoff yields because of important contributions from other areas in the watershed.

Table 6-2 shows the maximum possible street cleaning effort in the week immediately preceeding the observed storms, and the resultant expected runoff savings. This table summarizes specific rain characteristics. The actual loadings observed after the specific storms along with the projected estimated or actual loadings at the beginning of the next storm. Most of the storms shown on this table include the actual measured initial street surface loading values. The obtainable minimum street dirt loading before each storm (by using the maximum street cleaning program possible in the accumulation time between storms) is also shown. If this obtainable minimum street surface loading value is less than the observed or estimated loading values, then the street surface loading reductions and associated urban runoff discharge savings are shown. Table 6-3 summarizes the actual runoff mass yields and the calculated savings that could have been observed before each storm caused by the maximum street cleaning programs. This table shows that a maximum of about 20% of the total solids and about 35% of the lead could have been removed from the runoff.

Table 6-4 summarizes calculations showing the control of the total annual runoff yield possible for different street cleaning frequencies. Appendix D shows specific calculations for all of the constituents monitored and for various street cleaning programs. Again, these are based on actual runoff yield and street loading values and the expected street surface loading decreases obtainable by different street cleaning frequencies. This shows a total solids control of about 27% for three times a week frequency somewhat greater than the maximum value shown in Table 6-3.

TOTAL SOLIDS

TABLE 6-2 MAXIMUM POSSIBLE CLEANING EFFORT IN WEEK PRECEEDING OBSERVED STORMS AND RESULTANT RUNOFF SAVINGS

	Storm dates	Total Rain	Urban runoff (acre-ft.)	Fol. dry per. for street clean. before next storm (days)	Max.clean. program poss. in dry per. (passes per week)	After storm street ld. (lb./curb-mile	Actual or Est. ld. at beg. of next storm (lb./curb mile)	Obtainable min. str. ld. by max. clean. pro. before next storm (lbs./curb-mile)
	1979							
C	1/8	1.24	44	< 1	0	320	(D) 300(1)	-
D + E	1/10-14	4.01	79	2	1	360	360	650
F	2/13-14	1.20	29	1	0	440	(G) 520(1)	-
G + H + I + J	2/15-22	2.80	117	5	3	360	460	350
K	2/28-3/1	0.58	6.9	14	3	730	(L) 850(1)	350
L	3/15-17	0.75	9.5	10	3	430	(M) 870(1)	350
M	3/26-28	1.98	31	26	3	450	750	350
N	4/26	0.37	6.8	10	3	460	(I) 630(1)	350
1	10/18-19	0.99	20	5	3	410	460	350
3	11/3	0.56	28	13	3	170	(4) 260(1)	350
4	11/16-17	0.83	13	4	2	210	(5) 290(1)	450
5	11/22-25	0.73	24	24	3	140	(6) 640(1)	350
6	12/19-20	0.57	7.5	3	2	320	(7) 410(1)	450
7	12/23-25	3.52	140	5	3	280	(8) 410(1)	350
8	12/30-31	0.62	24	8	3	400	(9) 590(1)	350
	1980							
9	1/8-17	4.12	110	27	3	340	(10) 320(1)	350
10	2/14-24	5.94	340	4	2	220	(11) 340(1)	450
11	2/27-28	0.74	23	3	2	130	(12&13) 260(1)	450
12 + 13	3/2-6	1.27	43	18	3	300	(14) 470(1)	350
14	3/25	0.19	1.1	9	3	320	(15) 590(1)	350
15	4/4-5	1.06	29	14	3	490	(16&17) 840(1)	350
16 + 17	4/20-22	0.39	10	>100	3	510	1100	350

(1) Actual, the others based on accumulation rates.

TABLE 6-3. ESTIMATED MAXIMUM RUNOFF IMPROVEMENTS FOR MAXIMUM CLEANING EFFORT BEFORE EACH MONITORED STORM.

	TOTAL SOLIDS		LEAD	
Storm	Actual Runoff Mass (lbs.)	Savings w/Max. Cleaning Effort Before Storm (lbs.)	Actual Runoff Mass (lbs.)	Savings w/Max. Cleaning Effort Before Storm (lbs.)
D & E	65,600	0	-	-
G - J	119,000	0	80	0
L	6,990	28,900	6.7	40
M	26,500	26,900	21	40
1	26,500	14,500	29	45
4	6,890	0	29	0
5	9,090	0	29	0
6	4,710	15,000	28	19
7	48,100	0	8.5	0
8	14,400	3,100	32	1.6
9	128,000	12,400	36	15
10	217,000	0	286	0
11	33,700	0	18	0
12 & 13	44,500	0	28	0
14	688	6,200	1.8	12
15	10,100	12,400	14	16
16 & 17	11,520	25,300	15	45
	773,000	145,000	662	234

19% Savings

35% Savings

TABLE 6-4. CONTROL OF TOTAL ANNUAL RUNOFF YIELD AS A FUNCTION OF CLEANING FREQUENCY (MAXIMUM PERCENTAGES SHOWN)

Constituent	Monthly Street Cleaning	Weekly Street Cleaning	Twice Weekly Cleaning	Three Times a Week Cleaning	Greater or Equal to Four Times a Week
Total Solids	0.2%	7%	19%	27%	32
Lead	0.05	9	26	36	43
Zinc	2	4	8	10	12
Arsenic	0	6	15	21	25
Copper	0	<1	3	7	8
COD	3	5	8	11	13
Phosphorus	3	4	7	10	12
OPO_4	0	0	<1	<1	<1
TKN	0	1	2	3	4

The values shown in Table 6-4, however, do not consider the maximum possible cleaning effort that could occur during the preceeding dry accumulation period. However, the lead removal value of 36% for three times a week is very close to the maximum obtainable. Therefore, these values are all within reasonable limits even when considering the available time for street cleaning between storms. Therefore, if maximum urban runoff controls are going to be realized, then efforts should be made to clean the streets during the winter months between storms. If the street cleaning is rained out by a significant rain, it should be rescheduled. This problem is taken into consideration in these calculations. As expected, lead shows the greatest potential for control by street cleaning equipment, followed by total solids and then arsenic. Figure 1-4 in Section 1 illustrates this relationship and further shows that after about two or three passes per week any more street cleanding is unproductive. Zinc, COD, phosphorus, and copper can be controlled to a maximum of about 10%. Ortho-phosphates and total kjeldahl nitrogen can be controlled to a maximum of less than 10%.

The unit street dirt removal and runoff control costs for various street cleaning programs and for total solids are shown in Table 6-5. Appendix Tables G-1 through G-4 show the cost data for the other constituents. Figure 1-5 in Section 1 is a graphical presentation for the total solids information presented in Table 6-5. This table presents the total annual cleaning costs and the unit removal costs from street surface loadings. The annual runoff yield reductions and associated unit costs are also shown. This table also shows the effective yield, or the ratio between the amount of material removed from the street surface to save a given amount of material from the receiving waters. For total solids, this yield ratio ranges from between 5 and 18, depending upon the cleaning frequency. The annual costs shown in Table 6-5 assume a year-round constant-effort street cleaning program. These total costs, and therefore the unit runoff control costs, could be reduced by at least 25% by expending the most frequent street cleaning effort only immediately before the first rains of the year and during the winter rainy months. Summer street cleaning activities could be substantially reduced in order to meet only the aesthetic and traffic safety considerations of street cleaning programs.

Annual costs for the street cleaning programs increase linearly as a function of the cleaning frequency, or number of passes per year. However, the cost to remove a pound of street dirt from the street also increases dramatically with increased street cleaning. However, the cost to remove a pound of the same constituent from the receiving water does not follow the same pattern. After an initial steep rise in unit costs, going from zero to twice a month street cleaning, the unit costs actually decreases to prevent a pound of material from reaching the runoff water. This relationship is illustrated in Figure 1-5 in Section 1. After about three cleanings per week however, the unit cost sharply increases again. Therefore if the program costs can be justified, cleaning three times a week immediately before the first storm and between the other winter storms may give the best return for the money for total solids.

TABLE 6-5. UNIT STREET DIRT REMOVAL AND RUNOFF CONTROL COSTS FOR VARIOUS CLEANING FREQUENCIES

TOTAL SOLIDS

					Annual Runoff Yield Savings				
Cleaning Frequency	Passes Per Year	Annual Costs ($/curb mi)	Annual Removal (lbs/curb mi)	Unit Removal Costs ($/lb)	Annual Total Watershed (lb/yr)	Per Curb mile (lb/curb mi)	Portion of runoff Controlled (%)	Unit Savings Cost ($/lb Saved From receiving water)	Ratio (lb/ Removal to lb/ saved
Quarterly	4	$ 60	670	$0.09	6,000	120	1	$0.52	5.8
Monthly	12	180	2,000	0.09	8,500	170	2	1.10	12
2X/Month	24	360	4,000	0.09	12,000	230	2	1.60	18
Weekly	52	780	8,000	0.10	34,000	650	7	1.20	12
2X/Week	104	1,560	13,000	0.12	90,000	1,700	19	0.90	7.6
3X/Week	156	2,340	17,000	0.14	130,000	2,500	27	0.94	6.8
5X/Week	260	3,900	24,000	0.16	160,000	3,000	32	1.30	8.0
10X/Week	520	7,800	30,000	0.26	160,000	3,000	32	2.60	10
					COD				
Quarterly	4	$ 60	61	$1.00	2,500	47	2	$ 1.30	1.3
Monthly	12	180	180	1.00	3,000	55	3	3.20	3.2
2X/Month	24	360	370	1.00	3,200	60	3	6.00	6.2
Weekly	52	780	730	1.10	5,400	110	5	7.40	7.0
2X/Week	104	1,560	1,200	1.30	9,100	180	8	9.00	6.8
3X/Week	156	2,340	1,600	1.50	12,000	240	11	10.00	6.8
5X/Week	260	3,900	2,200	1.80	13,000	250	12	16.00	8.8
10X/Week	520	7,800	2,700	2.90	13,000	250	12	31.00	11

When reviewing Table 6-5 and Appendices G-1 through G-4 however, not all the constituents behave in the same manner. Chemical oxygen demand, total phosphorus, ortho-phosphates, and zinc all experience significantly increasing unit costs to prevent a pound of material from reaching the receiving waters. The other constituents however (total solids, total kjeldahl nitrogen, arsenic, copper, and lead) all show decreased unit costs with relatively frequent street cleaning programs. Similarly, the yield ratios also vary substantially for the different constituents. Total solids, COD, total phosphorus, ortho-phosphates, lead and zinc all require the removal of about ten times the material (a 10 to 1 removal ratio) from the street to save a given amount of material from the runoff water. Total kjeldahl nitrogen and copper however, can require the removal of almost 100 times the amount (a 100 to 1 removal ratio) from the street to save a given amount of material from the runoff water.

These large yield penalties are caused by the significant loss of street surface particulates from the street surface to the air which can then resettle on near by pervious areas or remain suspended. This resuspension is especially important during relatively long dry periods. If frequent street cleaning maintains the streets at low particulate loadings, these airborne emissions are substantially reduced. If long periods of accumulation do not have frequent street cleaning, however, large airborne losses can occur which prevent much of the deposited material on the streets from reaching the creeks when it rains. This can be important even for periods of time of about one week's duration.

The removal ratio is defined as the amount of material that must be controlled at the source area (the street surface in this study) to prevent a single unit of the material from entering the receiving water. This value varies for different pollutants, storm characteristics, and control measure characteristics. As an example, street cleaning well in advance of a storm (two weeks) has little effect on runoff quality, while street cleaning immediately before a significant storm prevents all the material removed from entering the receiving water. Runoff treatment at the outfall prevents all of the removed material from entering the receiving water, irrespective of the conditions. Other control measures also have unique removal ratio properties. Removal ratios were calculated for the different candidate street cleaning programs (cleaning frequencies) and all pollutants for the specific rains monitored during the two years of this project. These values are shown in Appendix Tables G-1 through G-4. The following discussion describes the information that was used to obtain these values.

Storm "F", which occurred on February 13 and 14, 1979 had a 27 day preceeding dry period, an observed urban runoff lead discharge of 19 pounds (corresponding to 0.37 lbs Pb/curb-mile), a before storm street surface loading of 1.22 lbs Pb/curb-mile, and a runoff volume of about 20 acre-feet. The obtainable before storm street surface lead loadings for different cleaning frequencies are given in Table 4-5 and are summarized below:

Passes per year	Passes per week	obtainable street load (lbs/curb-mi)
0	0	1.7
4	1/13	1.6
12	1/4	1.4
24	1/2	1.3
52	1	0.98
104	2	0.68
156	3	0.53
208	4	0.45
260	5	0.45
260	5	0.45

Therefore, only cleaning once per week or more frequently would result in probable street lead loading reductions before storm F. The runoff yield would still be 19 pounds for cleaning frequencies of less effort than once per week. The runoff improvement for once a week cleaning would be 1.22 lbs/curb-mile (the observed load) minus 0.98 lbs/curb-mile (the obtainable load). This value is 0.24 lbs/curb-mile.

The new runoff yield associated with the reduced street loading can be estimated from Figure 2-4, or Table 2-6. These illustrations relate the runoff volume to the street load to runoff yield ratio. The runoff volume for this storm was about 20 acre-feet, corresponding to an initial street load to runoff yield ratio of about 7.0. Therefore:

Initial street load/runoff yield = 7.0 = 0.98 lbs/curb-mile/runoff yield (expressed in lbs/curb-mile).

The new runoff yield for this storm would therefore be about 0.14 lbs/curb-mile or about 7.2 lbs lead (There are 52 curb-miles in the urban study area). The runoff yield savings for storm F, with weekly street cleaning, would therefore be 19 lbs - 7.2 lbs = 11.8 lbs. This corresponds to a percentage improvement for this storm of about 63 percent. This calculation can be performed for other cleaning frequencies and for all of the storms. Appendix Tables D-4 through D-12 show the total study period runoff control possible for various cleaning frequencies. The following list summarizes the total study period flow-weighted control possibilities.

Frequency	Max. lead improvement in runoff (lbs. for 2-yr. study)	percent
Monthly	<1	<1
Weekly	91	9
Twice a week	250	26
Three times a week	351	36

The new annual lead yield for these new cleaning programs can then be calculated, assuming a yield of 500 lb Pb/yr for the urban area (from Appendix Table E-5). These calculations are summarized below:

Frequency (Passes/yr)	Max. Percent Improvement	Max. Total Watershed Runoff Improvement (lbs/yr)	(lbs/curb-mile)
4	0	0	0
12	<1	0.3	0.005
24	1	5	0.1
52	9	46	0.9
104	26	130	2.4
156	36	180	3.4
260	43	210	4.0
520	43	210	4.0

The annual street lead removal is obtained from Figure 4-6 for different cleaning frequencies, assuming a street dirt lead concentration of 1600 mg/kg (from Table 2-2).

These removal values are compared to the runoff improvement values shown above for the different cleaning frequencies. The removal ratios are calculated by dividing the removal value by the runoff improvement and are summarized below:

Cleaning Frequency (Passes/yr)	Street Dirt Annual Removal (lbs/curb-mi)	Max. Runoff Improvement (lbs/curb-mi)	Min. Removal Ratio (Street removal to runoff improvement)
4	1	0	-
12	3	0.005	620
24	6	0.1	64
52	12	0.9	13
104	20	2.4	8
156	26	3.4	8
260	37	4.0	9
520	46	4.0	11

Removal ratios vary widely, depending on the pollutant, cleaning frequency, and specific storms in the study period. The following table summarizes the removal ratios calculated in this study (from Appendix Tables G-1 through G-4):

Pollutant	Removal Ratios for Cleaning Frequencies of 4 to 520 Times a Year			
	Min.	Max.	Value for Weekly Cleaning	Rank for Weekly
Copper	14	110	110	7
Lead	8	620	13	4
Arsenic	10	60	16	5
Zinc	1	9	6	1
Total Kjeldahl Nitrogen	22	120	42	6
Total Phosphorous	1	12	7	2
Ortho Phosphate	7	15	10	3

An alternative procedure to calculate street load effects on runoff yields was used to calculate the above values. This procedure results in maximum resultant runoff improvements. It assumes that all of the street dirt load reductions due to change in cleaning programs result in runoff improvements. This does not imply that all of the street dirt removed during the cleaning activities is "saved" from reaching the runoff (the removal ratio is not equal to one). Reductions in obtainable street loadings due to the different cleaning frequencies (as shown in Table 4-5) are multiplied by the study area size to obtain runoff reductions for each storm studied. These individual storm runoff improvements are totaled for the complete study period. This value is compared to the observed runoff yields to obtain an estimate of the maximum study period runoff improvement. As an example, Appendix Table D-5 lists the expected runoff improvements for lead with twice weekly street cleaning. Twice weekly street cleaning will result in lead street loadings of about 0.68 lbs/curb-mile. The following table summarizes some of the information presented in Appendix Table D-5:

Storm Number	Observed Initial Lead Street Load Before Storm (lbs/curb-mi)	Lead Street Load Reduction for 2X Week Cleaning (lbs/curb-mile)
F	1.22	0.54
G through J	0.75	0.07
K	0.97	0.29
L	1.33	0.65
M	1.26	0.58
N	0.91	0.23
1	1.41	0.73
3	1.10	0.42
4	0.44	0
5	0.48	0
6	0.91	0.23
7	0.50	0
8	0.56	0
9	0.81	0.13
10	0.48	0
11	0.50	0
12 and 13	0.41	0
14	0.77	0.09
15	0.83	0.15
16 and 17	1.35	0.67
	TOTAL:	4.78

The total maximum street load reduction of 4.8 lbs/ curb-mile corresponds to a total watershed load reduction of about 250 pounds each year for the two year monitoring period. The minimum new runoff yield would therefore be 976 lbs lead observed minus 250 lbs, or about 725 lbs. This corresponds to a maximum runoff improvement of about 25 percent for these conditions. This value is highly dependent on the storm characteristics and can change radically from one year to the next. This project monitored practically all runoff for two years. These procedures cannot be used in study areas where complete data for an extended period of time are not available. Very misleading results would be obtained, for example, if only storms of a specific volume are monitored. As mentioned above, these runoff improvement estimates are considered maximum values. Past studies (Pitt and Boxeman 1981 and Pitt 1982) have found that only about 75 percent of the observed street dirt is discharged to the receiving waters. The rest of the material is accumulated in the sewerage (catch-basins and pipe), but the amounts of material trapped varies for location and storm type.

The specific rainfall patterns observed during the two year study show how they can result in unique cost relationships. When the two years of data are analyzed separately, different conclusions can be obtained concerning optimal street cleaning frequencies and the times for cleaning to best control runoff contaminants. It is thought that the first year of study, with larger storms at the beginning of the rain year and then relatively smaller but longer duration storms later in the winter, is more common than the second year storm pattern. For the first year pattern, it would be more appropriate to try to have the most intensive street cleaning activities before the first major storms of the year, which typically occur in October. The street cleaning effort could then be reduced during the duration of the winter and then significantly reduced during the summer months.

The second year of study had uncommonly large storms occurring later in the rainy season. For the second year pattern, it would be better to sweep regularly and frequently all winter, then at a much reduced level during the summer. However, as noted previously, frequent street cleaning activities during the summer can substantially reduce the resuspension of street surface particulates and therefore reduce the resultant airborne particulate concentrations. In many parts of the county, these are important considerations and can be considered an important benefit of street cleaning operations.

Street Cleaning Program Changes

Many objectives should be taken into account when designing a street cleaning program for water quality purposes. Service area operating conditions (street surface conditions, land use, runoff characteristics and topography being most important) and the available equipment all come into consideration for determining the most effective street cleaning program for each area. The objectives of most concern in designing a street cleaning program include the environmental objectives of runoff water quality, air quality associated with fugitive dust emissions from dirty streets, and the noise emissions from the street cleaning equipment itself. The classical public relations, aesthetic and traffic safety objectives are obviously important considerations and usually define the minimum service levels for different study areas. If the public relations objective is the most limiting factor however, a significant effort to re-educate the service area residents concerning the importance of the other objectives such as water quality should be undertaken.

Much can be done to improve street cleaning operations within the existing street cleaning budget and available equipment. In very few cases would it be recommended that the currently available street cleaning equipment be exchanged for new equipment of a different generic type. Little real differences in equipment effectiveness exists for different equipment types. Much greater differences in equipment operation are associated with street surface types and conditions, speed of the street cleaning equipment, and most importantly, skill of the operator. The service area characteristics cannot be changed, except for parking regulations and road maintenance.

However, if the available on-street parking is occupied almost completely all of the time, then parking restrictions during the street cleaning time may actually result in reduced cleaning effectiveness by the street cleaning equipment (Pitt, 1979). This is because the relatively permanent row of parked cars can block much of the resuspended fugitive street surface particulates that would be blown off the street by winds and traffic induced turbulence in their absence. These particulates bounce off the cars and then fall onto the streets at a substantial distance away from the curb and outside of much of the street cleaning width. During conditions with no parked cars,some of this material is blocked by the curbs and falls next to the street near the curb. Therefore, during conditions with light to moderately heavy parking, parking controls can substantially increase the removal of partriculates by street cleaning equipment.

Another obvious improvement would be to decrease the level of service in those areas that have very frequent street cleaning (more than three passes per week) and increasing the cleaning frequency in those service areas having minimal cleaning and very dirty streets, such as industrial areas. The question of multiple passes of street cleaning equipment at less frequent rates was addressed earlier, and cannot be recommended because of the increased accumulation time between adjacent street cleaning passes. However, during winter months when the available accumulation period is restricted by rain, multiple passes may slightly improve the urban runoff controls available by street cleaning. A more interesting proposition may be to operate street cleaning equipment at twice the recommended speed, at 8 miles an hour, instead of 4 miles an hour, and then making two passes over the same area. These two passes would cost only slightly more than a single pass, and should be done at the same normal frequency. The decreased effectiveness of speeding up the equipment is not known, but it would most probably be more than offset by the multiple cleaning passes. A multiple pass consisting of one pass with a mechanical street cleaner followed by a regenerative air street cleaner could result in lower street surface loading values for all size fractions. However, this would be very costly and the marginally decreased loadings would probably not be justified. In conclusion, conditions, it seems that an evenly spaced street cleaning program using single passes is most appropriate for most conditions.

In the Bay Area, the most intense street cleaning effort should be expended during October (about three times per week in all areas, especially the dirtier areas) and then reducing this to once or twice per week during the remainder of the winter, with at least one or two passes between each rain event (possibly on the same day if the streets are very dirty from erosion). From May through September, the street cleaning program could be substantially reduced, to about one pass per month, to meet the aesthetic and traffic safety objectives, and to control fugitive particulate losses to a minimal extent. This strategy assumes that the observed first year rain conditions in Castro Valley were more typical than the second year. However, because of the potential for very large and long duration rain events in mid-winter, a relatively intense street cleaning program should be maintained during the rainy season.

Several factors must be considered if new street cleaning equipment is going to be purchased. The first thing to consider is that it is very likely that significant increases in receiving water quality or significant savings in street cleaning costs would be obtained for different generic types of equipment. However, not all of the effects of geographic areas and meteorological conditions were thoroughly evaluated when comparisons of different generic street cleaning equipment were made.

Removal Goals

The last part of Section 3 attempted to present a range for different removal goals, based on different criteria and viewpoints. Table 6-6 summarizes these various control goals for urban runoff, based upon these different objectives. The maximum control levels shown would result in maximum compliance with the standards, while the average control level would result in compliance with the standards about half the time, while the minimum control levels shown would result in no change at all in the number of times the standards were exceeded. All of the constituents shown have maximum control goals of greater than 90% for at least one of the criteria or methods of comparison. With such large removal goals, it is very difficult to select a control practice that would be totally acceptable. Unfortunately, levels of acceptable degradation for the various beneficial uses is not available. It is hoped that this information, if available, would result in substantially less urban runoff control goals.

Many of these criteria are not appropriate for urban runoff and for Castro Valley Creek. The aquatic life criteria may be applied, as aquatic life is a designated beneficial use of the creek but very little aquatic life currently exists because of physical constraints (low flows, large flow variations, and channel configuration and material). Castro Valley Creek is primarily used as a flood control channel to convey the runoff from the developed area quickly into the bay waters. If unit area emission criteria were applied, even then greater than 90% removals would be needed for all of the constituents. Therefore, it should probably be considered an impossible task to improve the quality of Castro Valley Creek water to meet any of these beneficial uses.

The ultimate receiving water for Castro Valley Creek and its associated urban runoff, is the South San Francisco Bay. San Francisco Bay does have many important beneficial uses, which are currently limited by degraded water quality conditions, especially in the South Bay. It is estimated that San Francisco Bay receives almost 25% of its suspended solids, more than 95% of its lead and 22% of its zinc discharges from urban runoff. However, less than 5% of the total organic matter and nutrient discharges coming into San Francisco Bay are associated with urban runoff. Most of the total phosphorus and nitrogen discharges are probably from treated municipal waste waters. Most of the organic matter, however, is probably from treated industrial discharges. Urban runoff, treated industrial waters and treated municipal waters individually account for about 30 to 40% of the suspended solids reaching San Francisco Bay (Pitt and Bozeman, 1981).

High bacteria concentrations are also usually associated with urban runoff, but were beyond the scope of this project to monitor. It therefore becomes more understandable and reasonable to compare urban runoff control goals based upon this important water resource (San Francisco Bay). Urban feeder creeks, similar to Castro Valley Creek, should probably be considered as flood control channels with goals of trying to keep them reasonably aesthetic and healthy, unless thay support important aquatic life populations or they drain into freshwater drinking water supply reservoirs.

TABLE 6-6. SUMMARY OF CASTRO VALLEY URBAN RUNOFF CONTROL GOALS

Major Urban Run-off Constituent	Level of Control (%)	Annual Unit Area Urban Storm Runoff to Equal Annual Non-urban Storm Runoff	Urban Sediment Quality Equal to Non-urban Sediment Quality	Knox Station (mostly urban run-off) Storm Runoff Water Quality Compared to Beneficial Use Quality Criteria: Irrigation	Livestock and Wildlife	Industrial	Aquatic Life	Marine Life	Recreation Uses	Freshwater Public Supply
Filterable Solids (TDS)	Min.	0		0		0				
	Avg.	71		0		0				
	Max.	95		0		39				
Non-filterable Solids (SS)	Min.	0					0			
	Avg.	70					68			
	Max.	94					87			
Ortho-Phosphates	Min.	0	-					100	0	
	Avg.	93	0					100	35	
	Max.	99	-					100	68	
Cadmium	Min.	0		0	0		0	0		0
	Avg.	77		0	0		0	0		0
	Max.	94		17	0		17	0		17
Chromium	Min.	0		0			0	0		0
	Avg.	68		0			0	0		0
	Max.	90		0			0	0		17
Copper	Min.	0		5	0		0	0		0
	Avg.	79		80	0		0	50		0
	Max.	95		97	29		86	93		0
Copper, dissolved	Min.			0	0		0	0		0
	Avg.			60	0		0	0		0
	Max.			94	0		71	86		0
Iron	Min.	0					80			94
	Avg.	69					89			97
	Max.	93					95			99
Lead	Min.	0	-	0	0		0			50
	Avg.	79	69	0	80		59			90
	Max.	90	-	0	97		94			98
Lead, dissolved	Min.			0	0		0			0
	Avg.			0	0		0			50
	Max.			0	86		71			93
Mercury	Min.	0			0		0	0		0
	Avg.	91			0		88	75		0
	Max.	98			60		98	96		20

Comparisons of Alternative Control Costs

A rough estimate was made to compare the relative unit costs of treating urban runoff, using various demonstrated urban runoff and erosion control measures. Inlet cleaning activities were also considered. Table 6-7 summarizes the projected 1979-1980 fiscal year costs for: a typical street cleaning program (from one to three passes per week), runoff treatment (the median values, including equalization but excluding collection), erosion control (the median values for forty tons/acre/year loss potential) and inlet cleaning once per year. These cost values vary widely for each of the pollutants but inlet cleaning appears to be the most cost-effective measure for most of the contaminants. Inlet cleaning appears to be most cost-effective because of the assumption that all of the material cleaned out of the inlet is saved from reaching the receiving water, whereas only relatively small fractions of the material saved from street cleaning and erosion control actually would be eliminated from the receiving waters (as discussed previously). However, all materials removed by runoff treatment would be saved from reaching receiving waters. It should be pointed out that the inlet cleaning measure is based on limited data.

Table 6-8 presents the limit of the potential controls possible for these control measures, along with the expected unit costs. Three different types of street cleaning programs, ranging from monthly to three times a week, are shown along with median runoff and erosion control treatments and once a year inlet cleaning. Again, the inlet cleaning seems to be the least costly, but unfortunately it can only affect about 2% of the total yields. Inlet cleaning may be increased to three or four times a year, with linear increases in cost, but would still be capable of only removing less than 10% of the total runoff yield. Three times a week street cleaning at a total annual cost of about $120,000 for the Castro Valley study area, could remove important amounts of total solids, arsenic and lead from the receiving waters, but these quantities are still much less than the total removals possible for runoff treatment. Annual runoff treatment costs would be about seven times as much as the maximum street cleaning costs (excluding collection system costs). Urban runoff treatment systems capable of treating all of Castro Valley could cost between five to ten million dollars per year for intermediate levels of treatment of common constituents (National Commission on Water Quality, December, 1975). The street cleaning costs shown here, however, assume constant street cleaning year-round and could be reduced by at least 25% by substantially decreasing the cleaning effort during the dry summer months.

TABLE 6-7. COSTS TO "REMOVE" A POUND OF CONSTITUENT FROM THE RECEIVING WATER
($/lb. controlled) - 1979/1980 COSTS

Constituent	Street Cleaning (1)	Runoff Treatment (2)	Erosion Control (3)	Inlet Cleaning (4)
Total solids	$1	$2	$5	$0.10
COD	8	12	250	0.50
Total Phosphorus	1,500	-	3,000	60
Ortho Phosphorus	35,000	900	-	-
Total Kjeldahl Nitrogen	2,500	600	5,000	700
Arsenic	100,000	-	-	-
Copper	50,000	-	-	-
Lead	800	-	-	80
Zinc	2,500	-	-	-

(1) this is much more expensive than removing a pound from the street, but considersyield.
(2) required separated sewers and few outfalls.
(3) the cost to control a pound at an erosion site is about 1/20 of these in-stream values.
(4) Source: Shawley, May, 1980

TABLE 6-8. POTENTIAL CONTROL AND COSTS OF VARIOUS URBAN RUNOFF CONTROL MEASURES

	Monthly Street Cleaning			Weekly Street Cleaning			Three Times a Week Street Cleaning		
	Potential Removal (lbs/yr)(1)	Unit Cost ($/lb)	% of Total Runoff Controlled	Potential Removal (lbs/yr)	Unit Cost ($/lb)	% of Total Runoff Controlled	Potential Removal (lbs/yr)	Unit Cost ($/lb)	% of Total Runoff Controlled
TOTAL COST ($):	$9,300			$40,000			$120,000		
Constituents									
Total Solids	8,500	1.10	2	34,000	1.20	7%	130,000	0.94	27%
COD	3,000	3.20	3	5,400	7.40	5	12,000	10.00	11
Total Phosphorus	20	480	3	28	1,400	4	60	2,000	10
Ortho Phosphates	0.3	28,000	0	1.3	32,000	0	3.0	42,000	0.2
Total Kjeldahl N	0	-	0	15	2,600	1	60	2,000	3
Arsenic	0	-	0	0.35	110,000	6	1.2	100,000	21
Copper	0	-	0	0.3	130,000	<1	5.0	24,000	7
Lead	0.3	36,000	0.05	46	860	9	180	680	36
Zinc	9.5	980	2	17	2,400	4	38	3,200	10

	Runoff Treatment			Erosion Control			Annual Inlet Cleaning		
	Potential Removal (lbs/yr)	Unit Cost ($/lb)	% of Total Runoff Controlled	Potential Removal (lbs/yr)	Unit Cost ($/lb)	% of Total Runoff Controlled	Potential Removal (lbs/yr)	Unit Cost ($/lb)	% of Total Runoff Controlled
TOTAL COST ($):	$800,000						$1,200		
Constituents									
Total Solids	400,000	2.00	75%	-	5.00	-(2)	12,000	0.10	2%
COD	68,000	12	50	-	250	-	2,000	0.50	1.5
Total Phosphorus	-	-	-	-	3,000	-	16	60	2
Ortho Phosphates	900	900	50	-	-	-	-	-	-
Total Kjeldahl N	1,300	600	40	-	5,000	-	4	700	0.1
Arsenic	-	-	-	-	-	-	-	-	-
Copper	-	-	-	-	-	-	-	-	-
Lead	-	-	-	-	-	-	12	80	2
Zinc	-	-	-	-	-	-	-	-	-

(1) Removal from receiving waters for 909 acres, 52 curb-mile study area.
(2) Typical erosion control is 75% of potential erosion loss at the site.

SECTION 7

DESIGN OF STREET CLEANING PROGRAMS FOR WATER QUALITY

This discussion summarizes the procedures that can be used to calculate the effectiveness of street cleaning operations in improving urban runoff quality. Street cleaning unit costs and the use of information from other areas are also briefly described. Simple tables and figures have been prepared to supplement this discussion. These are site specific to various degrees and are the basis for the important calculations in designing a street cleaning program. These figures are based upon observations from the two year Castro Valley NURP Project conducted in Alameda County, CA.

Figure 7-1 shows the accumulation of street surface particulates as a function of exposure time since the last street cleaning or significant rain. There can be significant scatter of the observed data for actual loading conditions. This is because of the effects of wind and traffic causing fugitive dust losses from the street surfaces. In addition, unusual loading conditions may also occur during a testing program caused by spills from trucks, leaves and other vegetative debris and erosion from non-street surfaces areas during light rain events. However, when all the data is carefully reviewed and plotted, general shapes similar to those shown in Figure 7-1 can be produced. The street surface particulate loadings usually increase rapidly soon after the streets are cleaned (0-10 days) or a significant rain, after which they increase at a slower rate. In many parts of the country, such long periods of dry accumulation as occurs in Castro Valley do not exist, and the usual two to three week dry spells that are more probable elsewhere results in generally straight accumulation curves.

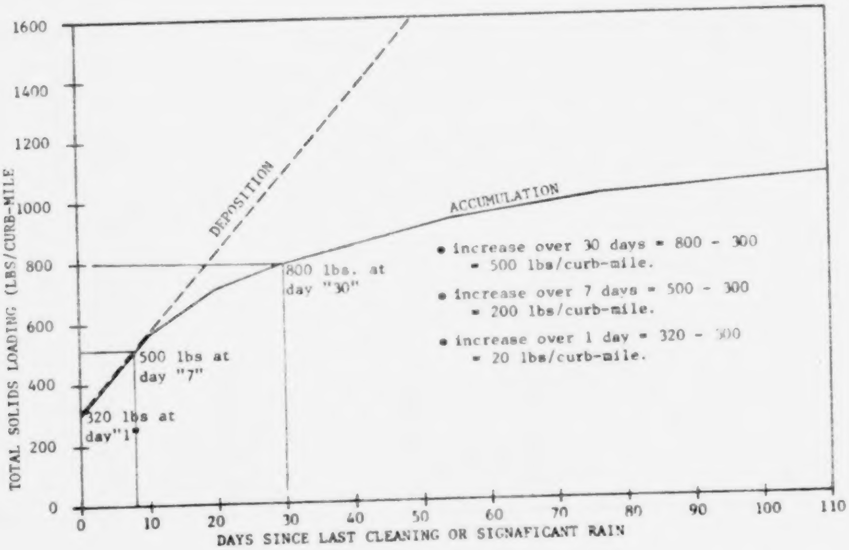


FIGURE 7-1. ACCUMULATION AND DEPOSITION RATES - TOTAL SOLIDS

Figure 7-1 also shows the deposition curve which is tangent to the initial accumulation curve section. This deposition rate is thought to be constant for a specific site and season as it is not dependent upon the loading on the street. However, after about one week the accumulation rate significantly decreases from this deposition rate, with the material not accumulating on the street which is easily lost as fugitive dust due to automobile traffic and high winds. Again, figures such as Figure 7-1 must be prepared for different test area characteristics and seasons. The most important test area characteristics are expected to be geographical i.e., street surface conditions and type, land use and topography. Meteorological conditions are also an important area characteristic that shape the accumulation deposition rate curves.

Figure 7-2 which is also based upon the specific Castro Valley data, relates initial street surface loading values (loadings before the streets are cleaned) to the residual loading values (the loading conditions observed after the streets are cleaned). Figure 7-2 shows the 95% confidence band around the median straight line relationship. This relationship has been found to be dependent mostly on street surface condition and type, land use and season. This relationship is less dependent on other factors such as topography and street cleaning equipment type. Parked car densities can also effect this relationship and should be studied. As shown, the percentage removal of street surface particulates can be high only if the initial street surface loadings are high. When the initial street surface loadings are low, the percentage removal values can be low.

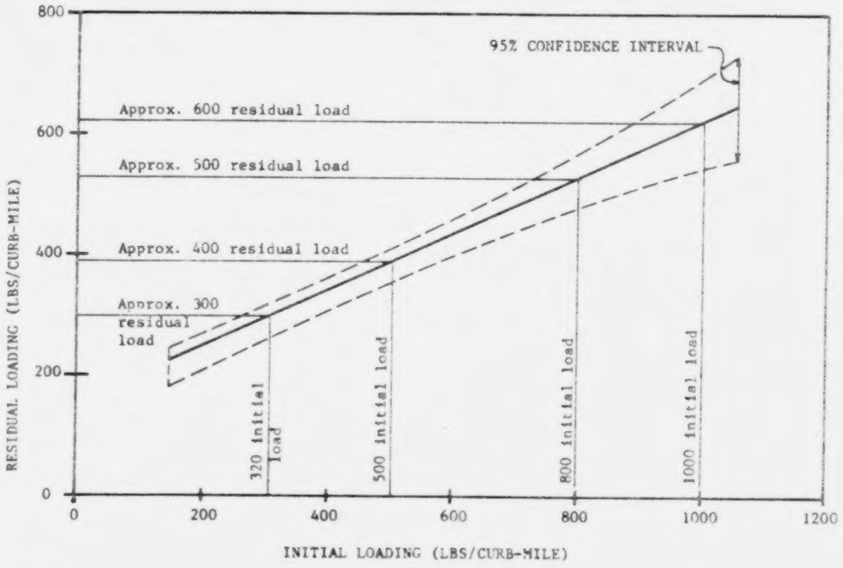


FIGURE 7-2. STREET CLEANER EFFECTIVENESS - TOTAL SOLIDS

Figure 7-3 is extremely site dependent for the Castro Valley Study Area and compares the ratio of the street surface loading values and the runoff yields to the runoff volume during a specific storm event. Figure 7-3 has high "R" squared values (0.80 for lead, 0.91 for total solids, 0.89 for COD and 0.92 for TKN). The "R"squared values for the other constituents monitored were also quite high approaching 0.98. These relationships of course are extremely site specific and are dependent upon the specific characteristics and erodibilities of the street surface particulates and upon street surface soil particulates. Erosion control practices, landscaping activities and the size of the monitored basins are all thought to change these specific values. Relating the street loading to runoff yield as a ratio to the runoff volume expressed in acre feet per acre instead of just total rainfall observed for a specific storm event resulted in more useable curve as it considers the antecedent dry conditions before each rain event along with the variable intensities of the different rain types.

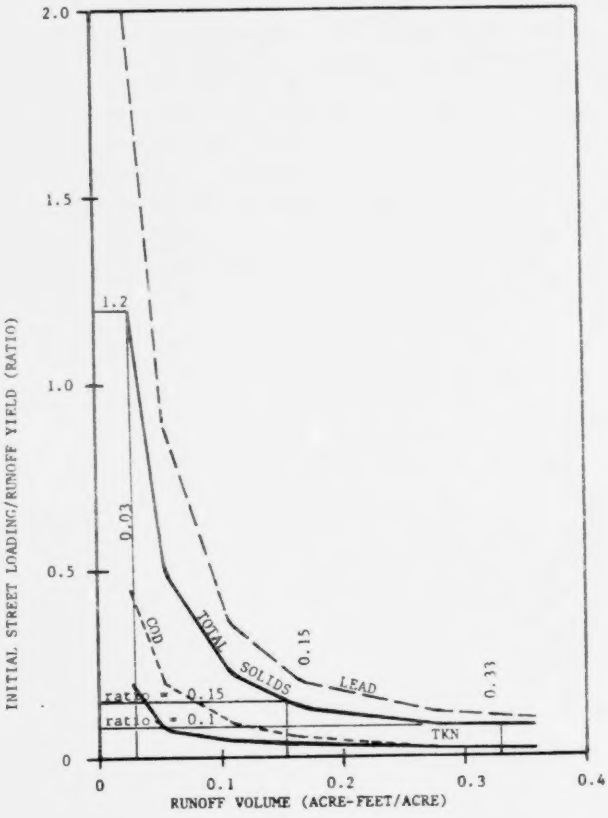


FIGURE 7-3: RUNOFF YIELD COMPARED TO STREET LOADING

When these three figures (7-1, 7-2 and 7-3) are available, a comprehensive methodology is available to determine the effectiveness of street cleaning programs for other time periods and locations studied. This procedure can be very useful in determining the most appropriate street cleaning programs for different service areas and seasons. These procedures can be used to develop street cleaning programs necessary to meet runoff allocation goals, the most cost effective unit removal costs or just the appropriation of available street cleaning dollars in the service area. This procedure can also be used to determine when and where service reductions should be made as decreasing budgets warrant.

The first step in this procedure is to determine the accumulation rates between adjacent street cleaning days. Figure 7-1 is marked with three examples for cleaning frequencies of one, seven and thirty days. In all cases, street surfaces have loadings of about 300 lbs. per curb mile after significant rains or after the streets have been cleaned quite frequently. For a one day program, the streets accumulate about 20 lbs. per curb mile between street cleanings, while the loadings can increase to about 500 lbs. per curb mile between cleanings on a 30-day street cleaning period. These values are shown on Figure 7-4 for these different cleaning frequencies. The resultant residual loadings (after street cleaning) are also shown based upon the values presented in Figure 7-2. This calculation is made for several series of street cleaning and accumulation periods in order to obtain the reasonable range of loadings of street surface particulates. As noted earlier, specific loading values can be much greater or much less than these shown, but these have been found to be quite consistent within the specific test area for a specific season. In all cases, reasonable minimum and maximum values are used in all calculations in order to obtain a reasonable expected range of conditions.

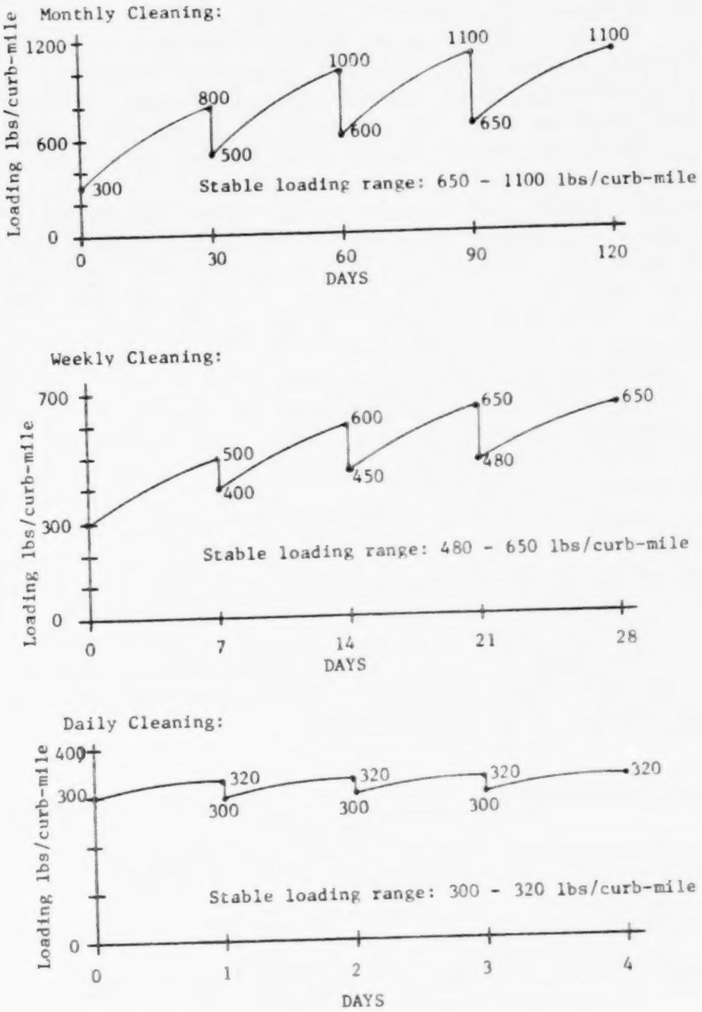


FIGURE 7-4. LOADING VARIATIONS FOR VARIOUS CLEANING PROGRAMS. (TOTAL SOLIDS)

Table 7-1 is an example, calculated for a hypothetical season and based upon three probable ranges of street surface loading conditions for these three different street cleaning programs. This hypothetical calculation assumes that there are 10 curb miles in the test basin or service area and also examines a simple selection of only three different storms within the study season. These 3 storms were selected because of their major differences in runoff characteristics and range from the very common small storms for the Castro Valley area to the very rare large storms. This simple calculation examines only one of each of these three storms while an actual calculation must be based upon an actual observed rain record for the season of concern with appropriate calculations for each rain. The ratio of street load to runoff yield for each of these three hypothetical rains was obtained from Figure 7-3, based upon the runoff yield expressed in acre-feet per acre. It is seen that this ratio is large for very small storms, but the ratio is quite small for larger storms. This means that larger storms are mostly made up of non-street surface particulates while smaller storms, because of the reduced hydraulic carrying capacity of the falling water, are only capable of cleansing the directly connected impervious surfaces (mostly streets). In other words, the larger storms are made up of mostly non-street surface erosion products, while the more common smaller storms are mostly made up of street surface particulates and sewerage deposition material. The material that has been deposited in the sewerage during previous large storms is available for transport by some of the smaller storms and most of the larger storms. That is why this ratio is greater than 1.0 for some storms. Table 7-1 uses these street load to runoff yield ratios and the total test area street loadings to obtain the range of runoff yields that can be expected for each of the cleaning programs. Again, in this simple case study these three storm types were added together to solely represent the one season under study. A more reasonable case would require an examination of the complete set of rains expected for an actual season.

TABLE 7-1 TOTAL SOLIDS RUNOFF YIELD FOR VAROUS CLEANING FREQUENCIES (FOR HYPOTHETICAL RAIN CHARACTERISTICS)

			Cleaning Every One-Day		Cleaning Every 7-days		Cleaning Every 30-days	
	Unit Street Loading (lb/curb-mile)	:	300	320	480	650	650	1100
	Total Basin Street Loading (lb.)*	:	3000	3200	4800	6500	6500	11000
List of all Storms for Period**	Runoff Yield (acre-ft/acre)	Street load to Runoff Yield (ratio)	Resultant Runoff Yield (lb)		Resultant Runoff Yield (lb)		Resultant Runoff Yield (lb)	
Lrg Storm	0.33	0.1	30,000	32,000	48,000	65,000	65,000	110,000
Med Storm	0.15	0.15	20,000	21,300	32,000	43,300	43,300	73,300
Sml Storm	0.03	1.2	2,500	2,670	4,000	5,400	5,400	9,200
Total Runoff Yield for Period (lbs):			52,500	56,000	84,000	114,000	114,000	193,000

* Assume 10 curb-miles in the basin.

** Example to show effects of different sized storms.

Figure 7-5 is a simple plot of the calculated expected urban runoff yields for this example season for the different street cleaning intervals. This figure shows a band representing the maximum and minimum probable total solids runoff yields. Table 7-2 shows how this figure can be used to calculate the most appropriate street cleaning program, based upon different objectives. This table shows the resultant median runoff yield for this storm period for different types of street cleaning programs along with the resultant runoff load savings and the percent control values. Again, this is for a hypothetical example and the actual control effectiveness are obviously very dependent upon specific site characteristics especially the rainfall conditions during the study period. This table also shows an estimated quarterly program cost for this ten curb mile service area, assuming a unit cost of $15.00 per curb mile. The unit cost, or dollars per pound of runoff pollutant saved, for the different cleaning programs is also shown. In this example, a cleaning frequency of once per week is the most cost-effective, with a resultant cost of about $0.04 per pound of total solids saved from entering the runoff water. If the cleaning frequencey increases to daily cleaning, this can increase by a factor of three or four. If the street cleaning program is practically eliminated (cleaning about once per month) this unit runoff water quality saving cost can be extremely high because of the very ineffective nature of a very low effort street cleaning program.

As mentioned previously, this is an example based upon a very simplified seasonal rainfall set of conditions, but it is also based upon actual observed relationships from Castro Valley. Similar procedures to these were used in the data analyses for calculating the street cleaning effectiveness in the Castro Valley NURP Project. A very complete rain record was obtained and these calculations were made for a broad list of urban runoff constituents. This procedure can be used to optimize existing street cleaning programs, or it can show how programs can either be increased or decreased, depending upon the available resources. This technique would obviously have to be repeated for each service area, and for each season.

By using the procedures herein described, public works officials can calculate the effectiveness of their particular street cleaning operations. These procedures allow development of a strategy for control of urban runoff by providing the calculations to determine the design of street cleaning programs to improve urban runoff quality.

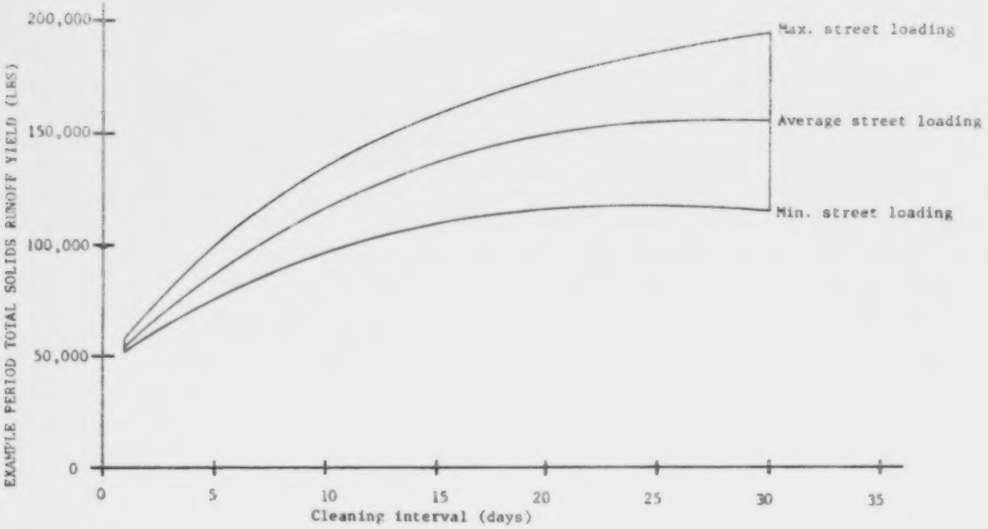


FIGURE 7-5. EXAMPLE PLOT OF RUNOFF YIELD AS A FUNCTION OF CLEANING INTERVAL.

TABLE 7-2. EXAMPLE CALCULATION TO ESTIMATE RUNOFF CONTROL EFFECTIVENESS FOR HYPOTHETICAL RAIN CHARACTERISTICS AND VARIOUS STREET CLEANING FREQUENCY FOR TOTAL SOLIDS

Cleaning Frequency (passes per quarter)*	Cleaning Interval (days)	Runoff Load for Period (lbs)	Runoff Load Savings (lbs)	Percent Control**	Total Quarterly Program Cost ($) ***	Unit Cost ($/lb Runoff Load Savings)
91	1	54,000	101,000	65%	$13,700	0.14
31	3	71,000	84,000	54%	4,600	0.05
13	7	100,000	55,000	35%	2,000	0.04
7	14	134,000	21,000	14%	1,000	0.05
4	21	150,000	5,000	3%	650	0.13
3	30	155,000	0	0	450	0.0
0	91	155,000	0	0	0	--

* Cleaning frequency is a measure of relative program cost.

** As noted, this is for a hypothetical example case. The actual control effectiveness is dependent on specific site characteristics and the rainfall conditions during the period of study. The control effectiveness calculations should be repeated for actual site specific and rainfall conditions.

*** Assuming 10 curb-miles in the Study Area and each pass costs $15.00 per curb-mile cleaned.

SECTION 8

ASBESTOS IN THE CASTRO VALLEY URBAN AREA

INTRODUCTION

A detailed investigation of asbestos fibers was conducted as part of the Nationwide Urban Runoff Program (NURP) in Castro Valley, California. The objectives of this study were to determine the asbestos sources in urban areas, how the asbestos can be controlled and the fate and movements of asbestos fibers.

A special laboratory program was designed to analyze asbestos in rural and urban soil samples (from construction sites, landscaped areas and vacant lots), particulate samples collected from "source" areas (such as rooftops, parking lots, street surfaces, large paved areas and driveways), stormwater runoff, creek water and sediment samples. About 90 samples were analyzed with a screening procedure which involved polarized-light microscopy with dispersion staining and qualitative transmission electron microscopy. None of the samples had detectable asbestos fibers using the optical microscope procedures, but many of the samples contained significant quantities of small asbestos fibers that were observable using electron optics. Twenty-two samples were further analyzed using EPA specified procedures (transmission electron microscopy with selected-area electron diffraction-TEM/SAED). The TEM/SAED procedures resulted in complete and confirmed fiber characterization (asbestos fiber type, fiber length, fiber diameter, fiber concentration and fiber weight).

The creek and stormwater fiber concentrations were as high as 300 million fibers per liter, but averaged about 25 million fibers per liter. The fiber lengths were about 1-1/2 microns. The calculated asbestos fiber yields (Chrysotile asbestos) was about 10^{13} fibers per acre per year in the stormwater. Street surface particulate asbestos fiber concentrations averaged about 300 million fibers per liter, but averaged about 300 million fibers per gram, with fiber lengths of about one micron. The accumulation rate was about 5×10^{12} asbestos fibers per curb-mile per day. About 40 percent of this street surface asbestos was due to vehicle deposition (brake and clutch wear) and about 70 percent was lost to the air as fugitive dust (much of which would settle on adjacent soils). Asbestos was found in significant concentrations in most of the other source area particulate samples; averaging from 50 to 1000 million fibers per gram. These fibers were also short (about one micron in length) and were almost all of the Chrysotile asbestos type (the common commercial form of asbestos).

An extensive literature search was also conducted to identity asbestos sources (natural and "man-made"). Information was also obtained concerning the effects of asbestos (inhalation and ingestion) and the fate and movement of asbestos fibers in the environment.

The study concluded that large numbers of short asbestos fibers can be found throughout an urban area that does not contain any appreciable natural asbestos sources. The major sources of asbestos in Castro Valley are probably automobile wear and asbestos roof material decomposition. Demolition of buildings containing asbestos insulation may also be an important, but irregular asbestos source. The disposal of asbestos containing solid wastes in municipal landfills is usually the most important recognized asbestos source/fate (depending on disposal practices) in urban areas. The small sizes of the asbestos fibers that were commonly found probably limit their environmental and public health effects. However, adaquate non-occupational asbestos exposure criteria are very limited.

FIELD AND LABORATORY PROCEDURES

A special analytical program was designed which involved collecting and analyzing samples of street surface particulates and urban runoff. Samples were also collected throughout the urban and rural portions of the study area to describe asbestos concentrations in native soil and from areas such as roof tops, parking lots, and landscaped areas. The runoff and street surface samples were obtained as part of the normal NURP field program (no special procedures were used in their collection or handling). The sampling of soils and other source areas required additional field activities. Surface soil samples were obtained by using a trowel. Particulate samples from paved areas were collected using the vacuum collection equipment normally used in the street surface sampling activities (described in the main report).

A two-phased approach was employed for sample analyses. All samples were initially analyzed using a pre-screening procedure which used both optical and transmission electron microscope procedures. Samples that were found to contain asbestos fibers were then subjected to more detailed transmission electron microscope and selected-area electron diffraction (TEM/SAED) procedures to better quantify the asbestos.

Eighty-nine samples were submitted for pre-screening tests, including 17 urban runoff samples (11 from the Knox station* and 6 from the Seaview station). Fourteen soil samples were obtained, each made up of about five sub-samples. Two vacant lots and two construction sites were sampled in the urban area. Six rural soil samples were obtained above the Seaview monitoring station. Four soil samples were also obtained from landscaped areas in the urban study area. One composite sample was made up of school turf sub-areas, another composite from about five residential lawn areas, a third from a landscaped park area, and a fourth from sub-samples collected in several residential gardens.

In addition, six samples of Castro Valley Creek bottom sediment were also obtained for pre-screening analyses. Two were taken in the rural area and four in the urban area. Each sample was composited from about three sub-samples collected from locations in the stream bed which were approximately 50 yards apart.

Nine control area samples were also obtained. These included four rooftop samples (each of which was composited from about five different roofs). A composite sample was obtained to represent a variety of commercial roof types. One residential wood shingle roof and two residential asphalt shingle roof groups (old and new) were sampled. Control area samples were also obtained from five other areas, including paved parking lots, unpaved parking lots, paved driveways, unpaved driveways, and paved school playgrounds.

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*Sampling locations are described in the Main Report.

In addition, 42 street surface samples, representing different particle sizes composited during the first and second years of the study, were also pre-screened to look for asbestos fibers. From the 89 initial samples described above, 22 were selected for further detailed analyses using the more sophisticated TEM/SAED procedures. These 22 samples were selected to represent each of the sub-groupings submitted for the pre-screening tests (i.e., 5 runoff samples, 3 soil samples, 2 creek sediment samples, 7 control area samples, and 5 street surface samples).

Appendix H describes EPA's recommended procedures for sample collection, field preparation, and laboratory analyses for asbestos fiber determinations in water. Although the procedures used in this study varied somewhat from those described in Appendix H, the more standard procedures are included because they generally guided the work reported here. Appendix H focusses primarily on field activities because standardized laboratory procedures are still under review and subject to revision.

As noted previously, most of the samples analyzed in this project were obtained during the normal sampling program of the NURP project. Special compositing procedures for water and street surface particulate samples were used to assure that the resultant data would be comparable to the other consitutent data presented elsewhere in the main report. Care was used to minimize contamination of samples. The soil samples were obtained with a trowel and immediately put into sampling bags for shipment to the laboratory. Particulate samples from paved areas were collected using the vacuum collection equipment used for street surface particulate sampling and were also immediately placed in sample bags for shipment to the laboratory.

11 of the samples were subjected to a pre-screening procedure which involved polarized-light microscopy, with dispersion staining. An aliquot of each sample was taken after thorough shaking. The aliquots were then allowed to settle for five minutes, a drop of the sample was removed from the surface, dried on a coated grid, and the residue examined with a transmission electron microscope. This procedure was designed to determine the presence or absence of asbestos fibers in the sample.

Although none of the samples had asbestos fibers that were detectable by optical procedures, a great number of the samples had asbestos which was revealed by the TEM/SAED procedure. This finding confirmed that optical techniques are inadequate for the identification of asbestos in small quantities, especially for small fiber sizes. Optical techniques for asbestos analyses were developed mainly for assessing occupational exposure. In such assessments, the enumeration of the fibers is of low priority, and the fibers are generally present in abundance and are of large size (consisting primarily of bulk insulation). The counting procedures are simplified and the observation error is greatly reduced by looking only at fibers greater than 5 microns (Langer, et al. 1978). Millette, et al. (1979) states that polarized light microscopy with dispersion staining may be useful in analyzing samples containing asbestos fibers longer than 0.3 microns, but the asbestos fibers in water are generally smaller than the resolving power of light microscopes.

In studying asbestos in relatively unpolluted water and air, it is necessary to use techniques that will measure small particles; i.e., electron microscope procedures. Direct magnifications of at least 20,000 to over 40,000 power are probably necessary (Selikoff, 1972). Selikoff further states that, while optical microscopy may be suitable as a guide for assessing occupational exposure, it has insurmountable inadequacies for studying asbestos pollution of ambient air. Again, the same problems would occur for water containing small quantities of small asbestos fibers.

Another problem of evaluating analytical procedures is to select one that can easily count large quantities of all fibers. Laboratories usually prefer to count approximately 100 asbestos fibers per sample to reduce the measurement error to a small level in relationship to the total (Millette, et al. 1979). Unfortunately, in many samples, it is impossible to search long enough to find that many fibers. When the total fiber count is less than five fibers, the counting statistics are extremely unfavorable, with the upper and lower confidence limits at about plus or minus 100 percent. For example, most of the 22 samples from this study that were subjected to the detailed TEM/SAED analyses had total fiber counts of more than 40 fibers. However, two samples did involve only counting eight fibers, and another sample involved counting only fourteen fibers. Therefore, the statistical confidence limits (based upon a Poission distribution of the fibers on the filter) are quite good; they were near optimal for about 75 percent of the samples.

One of the main reasons for using the two-phase combination of laboratory procedures is the high cost of the TEM/SAED analyses (between $300 and $500 per sample). The pre-screening procedure was substantially less expensive (about $50 per sample) but still included both the important transmission electron microscope analyses and the polarized light microscopy with dispersion staining. The pre-screening TEM/SAED method provided semi-quantitative results. The "light" or "occasional" grouping had five to ten asbestos fibers in a grid square but not every grid had fibers. "Trace quantities" included one to two fibers in six to ten grid squares. "Light-to-moderate" counts were on the order of twenty to fifty fibers per grid square, with some fibers usually found under other debris. "Numerous" or "heavy" asbestos fiber loadings had more than one hundred fibers per square.

From six to ten grid squares were examined for each sample. If the dispersion of the fibers was uniform and if there were several fibers in every square, six grid squares were examined. For other samples, ten grid squares were examined. The pre-screening procedure also resulted in a description of the presence of other fibers observed by the optical or by the electron microscope. Most of the other material present was found to be rock-forming minerals and plant material. The transmission electron microscope allowed the observation of non-asbestos fibers, diatom fragments, and other debris.

Many of the samples that had positive asbestos counts using the screening procedures were further analyzed by the EPA-approved TEM/SAED procedures. This rigorous procedure provided information on the total number of chrysotile and amphibole asbestos fibers present, the total asbestos fiber mass, the distribution of fiber lengths and widths, and the fibers' aspect ratios (length to width ratios). The complete laboratory results for the prescreening and the TEM/SAED procedures are presented in Appendix I.

Figures 8-1, 8-2, and 8-3 are electron micro-photographs, from 30,000 to 50,000 power, showing selected asbestos fibers for a rooftop sample, a runoff water sample, and a street surface sample. In all three cases, the characteristics of the particles and the fibers are quite similar, as shown in the photographs. Figures 8-2 and 8-3 clearly indicate the hollow tube configuration which is characteristic of chrysotile fibers. The size and shape of the asbestos fibers were also found to be quite similar for all of the samples examined in this study.

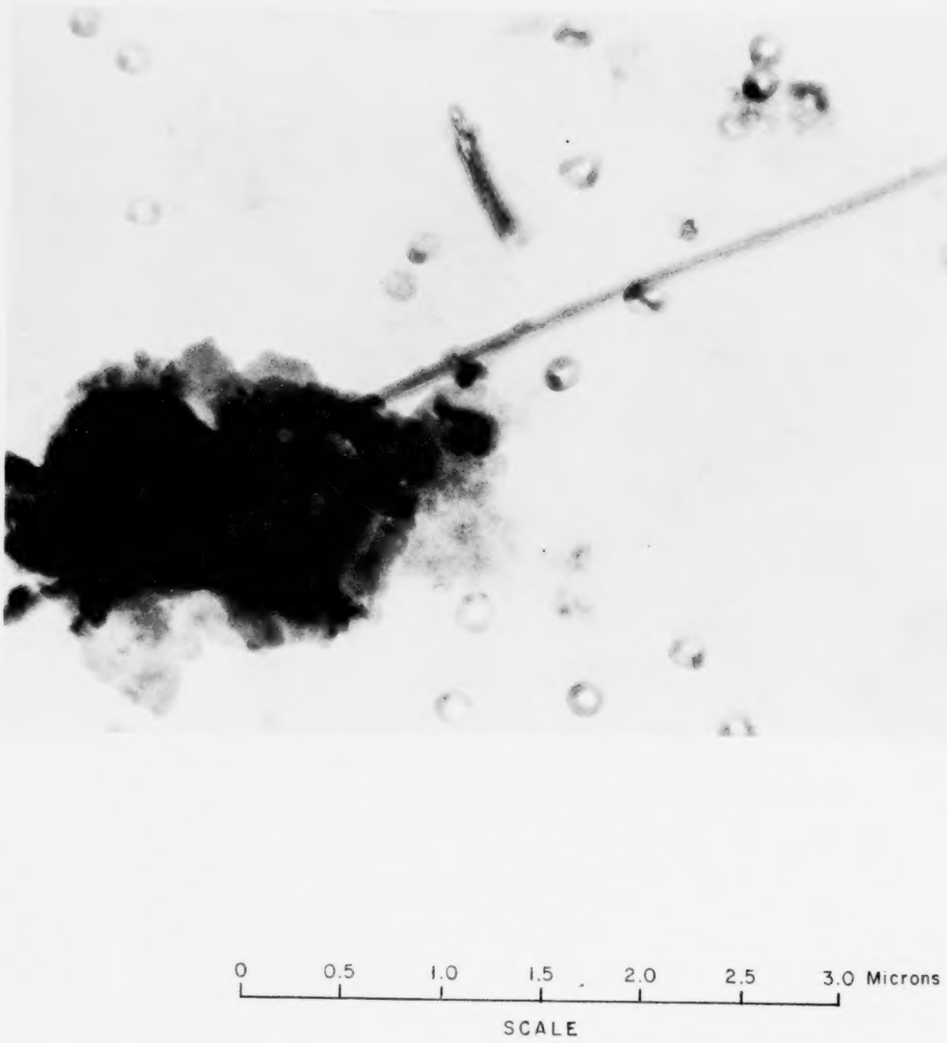
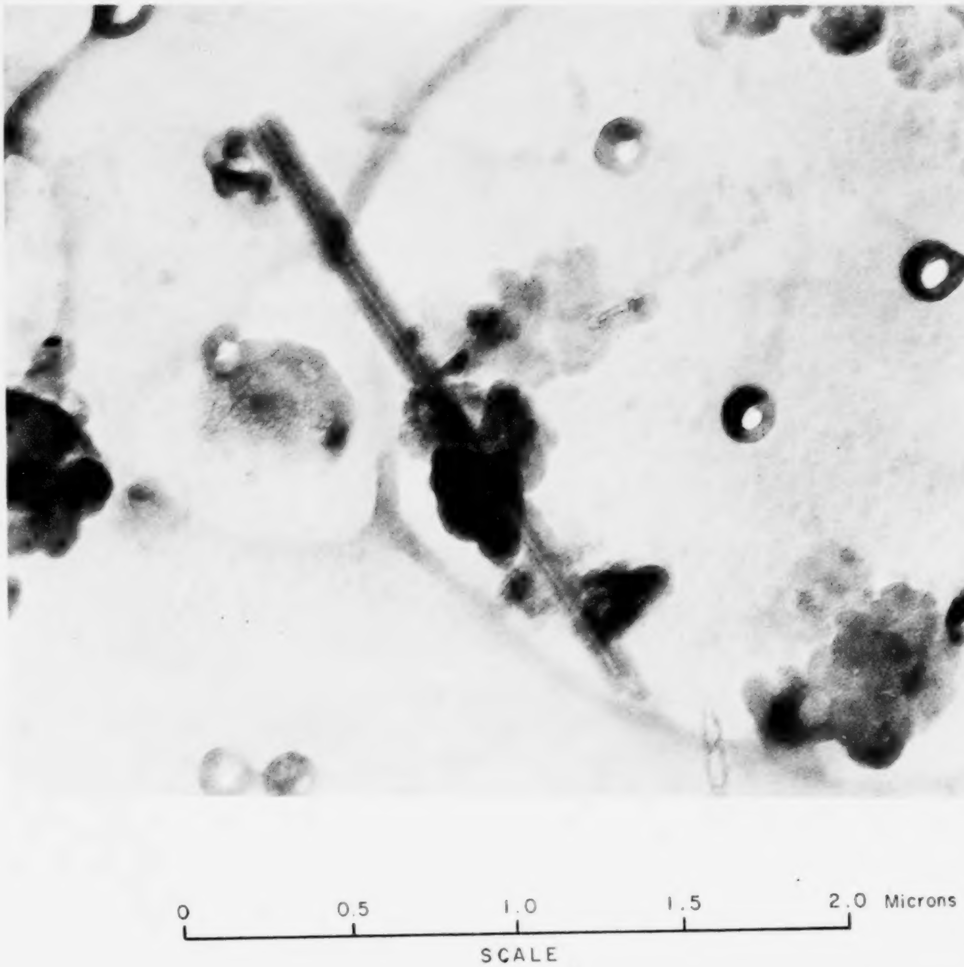

0
0.5
1.0
1.5
2.0
2.5
3.0 Microns
SCALE

FIGURE 8-1 ASBESTOS FIBER OBSERVED IN ROOFTOP SAMPLE.
(COMMERCIAL ROOF COMPOSITE)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0.5
1.0
1.5
2.0 Microns
SCALE

FIGURE 8-2. ASBESTOS FIBER OBSERVED IN RUNOFF WATER SAMPLE. (APRIL 23,1980 KNOX STATION).

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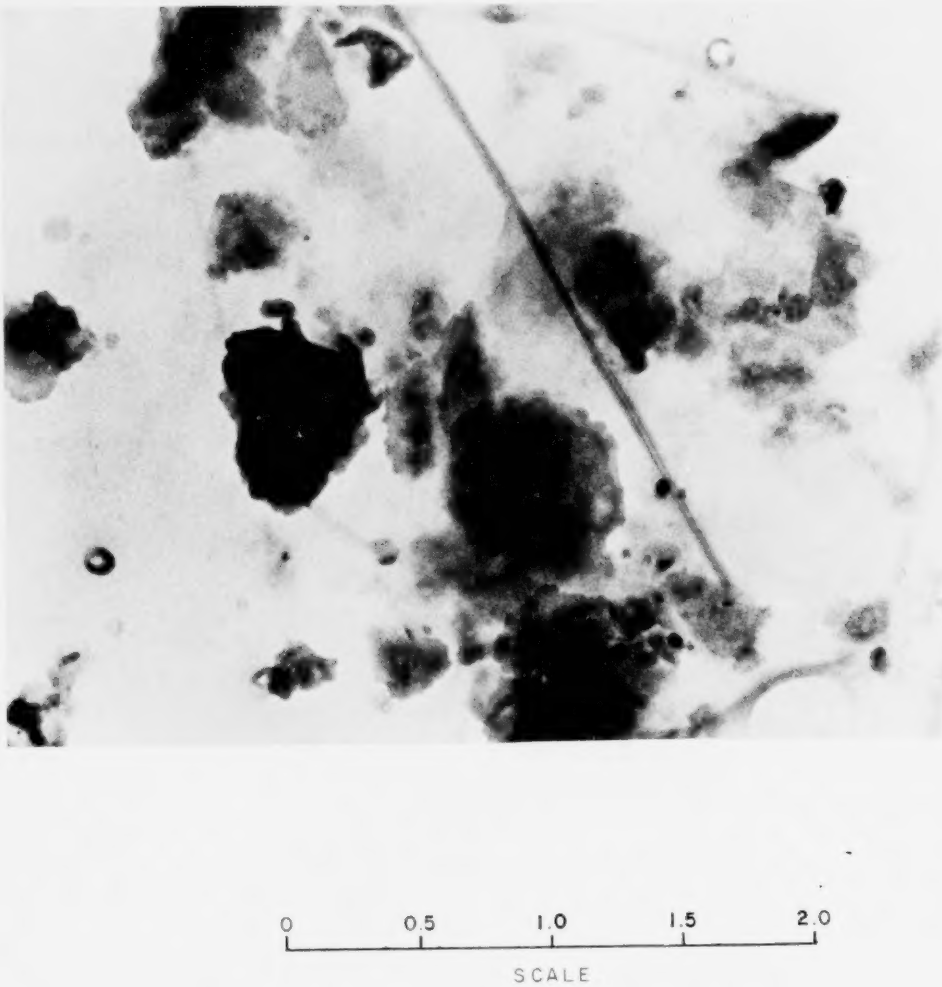
0
0.5
1.0
1.5
2.0
SCALE

FIGURE 8-3. ASBESTOS FIBER OBSERVED IN STREET DIRT SAMPLE. (MIDDLE AREA, SECOND YEAR COMPOSITE, 106 TO 250 MICRON PARTICLE SIZES).

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RESULTS OF CASTRO VALLEY STUDIES

Asbestos in Urban Runoff

Table 8-1 summarizes the asbestos fiber characteristics observed and calculated for urban runoff from the Castro Valley Creek watershed. Information is shown for the monitored creek flows of Castro Valley Creek at both the Seaview and Knox stations. The table also presents urban runoff characteristics which were calculated by the difference (or pro-rated) between the two stations. Between 2/3 and 3/4 of the total second-year storm runoff flows were monitored for asbestos fibers by the screening method.

About 10 percent of the monitored flows had detectable asbestos fibers. The annual average asbestos fiber concentration in the urban runoff was about thirty million fibers per liter. The overall range, however, varied from less than three hundred thousand to more than three hundred million fibers per liter.

Almost all of the asbestos fibers observed were of the chrysotile type, with less than 10 percent of the observed asbestos fibers being amphibole asbestos. The calculated asbestos concentrations varied from about three to five micrograms of asbestos per liter. The unit fiber weights ranged from about 1.3 to about 50 million fibers per microgram. The average for urban runoff was about 25 million fibers per microgram.

The TEM/SAED procedures also detected total asbestiform fibers in the runoff samples. The predominant fibers of the asbestiform type were found to be non-asbestos. The TEM/SAED procedure also indicated the numbers of asbestos fibers that were of restricted size (i.e., greater than 5 microns in length and less than 1/2 micron in width). Almost all of the fibers detected were shorter than this length. As noted in a later sub-section there is some controversy concerning the effect of small vs. long asbestos fibers. The median chrysotile fibers were about 1 1/2 microns long and slightly less than 1/10 micron wide. The overall length of all chrysotile fibers observed ranged from about 1/2 micron to greater than 2 1/2 microns. The calculated annual asbestos fiber yield for the urban area was approximately 3×10^{16} fibers per year. This corresponds to approximately 3×10^{13} fibers per acre per year. These results indicate that urban runoff contains significant quantities of asbestos fibers; considerably higher than the concentrations of asbestos in most natural waters and in municipal tap waters (which are described later in this section).

The complete laboratory results for the asbestos analyses are presented in Appendix I. Table I-1 shows the screening results for the runoff analyses for almost all runoff that occurred during the second project year. Those samples that had obserable asbestos using the TEM/SAED screening procedure were further analysed using the complete EPA approved TEM/SAED technique, as described in Appendix H. Table I-5 presents the complete TEM/SAED results for all samples, including the runoff samples. Table 8-A summarizes the observed runoff asbestos concentrations for the second year storms that were analyzed for asbestos, along with the runoff volumes.

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TABLE 8-1. CASTRO VALLEY CREEK AND URBAN RUNOFF ASBESTOS FIBER CHARACTERISTICS AND YIELDS

Characteristics and units	Castro Valley Creek at:		Urban Runoff (by difference)
	Seaview Station	Knox Station	
Percentage of second year flow monitored for asbestos fibers	67%	74%	66%
Percentage of monitored flow having detectable asbestos fibers	7%	12%	--
Annual average asbestos fiber concentration (10^6 fibers/l)	15	25	30
Range of observed asbestos fiber concentrations in all samples (10^6 fibers/l)	<15 152	<0.3 319	--
Percentage of total observed asbestos fibers that were Chrysotile asbestos	100%	92%	91%
Percentage of total observed asbestos fibers that were Amphibole asbestos	0%	8%	9%
Asbestos weight concentration (μg asbestos/liter)	3	5	--
Asbestiform[1] fibers as a percentage of the total asbestos-form plus asbestos fibers	91%	64%	--
Percentage of asbestos fibers that were of "restricted"[2] size (>5μ length and <0.5 μ width)	0%	2%	--
Median Chrysotile particle length[3] (μ)	1.3	1.4	1.4
Median Chrysotile particle width[4] (μ)	0.09	0.08	0.08
Median Chrysotile particle aspect (length/width ratio)	17	17	17
Annual asbestos fiber yield (fibers/year)	3×10^{15}	3×10^{16}	3×10^{16}

Table 8-1. (concluded)

Characteristics and units	Castro Valley Creek at: Seaview Station	Castro Valley Creek at: Knox Station	Urban Runoff (by difference)
Annual asbestos fiber unit area yield (fibers/acre/year)	$5x10^{12}$	$2x10^{13}$	$3x10^{13}$
Unit fiber weights (10^6 fibers/μg) (average and range)	48	26(1.3 37)	24

[1] Asbestiform fibers are any fibers having an aspect greater than or equal to 3.0.

[2] "Restricted" fibers are the most hazardous, at least from an air quality criteria.

[3] Overall lengths ranged from 0.5 to >2.5 .

[4] Overall widths ranged from 0.05 to >0.25 .

[5] Overall aspects ranged from <10 to 50 .

TABLE 8-A. RUNOFF ASBESTOS CONCENTRATIONS AND OBSERVED FLOWS

Date	Asbestos Concentration (10^6 fibers/l)	Flow (acre-ft)	Weighted Flow X Conc. (acre-ft-10^6 fibers/l)
KNOX:			
11/3/79	22.1	38.4	810
11/17	<5	13.2	<66
11/30	<5	23.9	<120
12/21	<5	7.5	<38
12/26	<5	153.7	<769
12/31	<5	23.9	<120
2/25/80	<5	434.9	<2,175
2/28	<5	29.5	<148
3/4	114	17.2	1,960
3/7	319	38.7	12,345
4/23	7.6	3.5	27
Total		788.4	15,142 to 18,578
Min. Flow-Weighted Conc. = 15,142/788.4 = 18 X 10^6 fibers/l			
Max. Flow-Weighted Conc. = 18,578/788.4 = 24 X 10^6 fibers/l			
SEAVIEW:			
11/30/79	<5	0.1	<0.5
12/26	<5	13.2	<66
2/25/80	<5	91.8	<459
2/28	<5	7.0	<35
3/4	<5	4.1	<21
3/7	152	9.3	1414
Total		125.5	1414 to 1996
Min. Flow-Weighted Conc. = 1414/125.5 = 11 X 10^6 fibers/l			
Max. Flow-Weighted Conc. = 1996/125.5 = 16 X 10^6 fibers/l			

The calculated flow-weighted asbestos concentrations are therefore 18 to 24 million fibers per liter for the Knox station and 11 to 16 million fibers per liter for the Seaview station. The corresponding values in Table 8-1 (15 and 25 million fibers per liter for Seaview and Knox respectively) are rounded values, due to the relatively high analytical uncertainty of asbestos analyses. The calculations in Table 8-A use a typical detection limit of 5 million fibers per liter, but the detection limit, as shown on Table I-5, varied from 0.3 to 15.2 million fibers per liter. The detection limit varies greatly, depending on the sample volume analyzed. The corresponding estimated urban runoff asbestos concentration estimated urban runoff asbestos concentration is calculated on the mas balance; Knox mass equals Seaview mass plus urban runoff mass:

$$C^u = \frac{(C^kF^k - C^sF^s)}{F^u}$$

where C^u is the urban runoff concentration

C^k is the concentration at Knox

C^s is the concentration at Seaview

F^u is the urban runoff flow

F^k is the flow at Knox

and F^s is the flow at Seaview

The minimum urban runoff asbestos concentration is therefore:

$$\frac{(18 \text{ X } 10^6 \text{ fibers/liter})\ (1.31 \text{ X } 10^9 \text{ liter}) - (16 \text{ X } 10^6 \text{ fibers/liter})\ (2.3 \text{ X } 10^8 \text{ liter})}{(1.08 \text{ X } 10^9 \text{ liter})}$$

= 18 million fibers per liter

and the maximum urban runoff asbestos concentration is:

$$\frac{(24 \text{ X } 10^6 \text{ fibers/liter})\ (1.3 \text{ X } 10^9 \text{ liter}) - (11 \text{ X } 10^6 \text{ fibers/liter})\ (2.3 \text{ X } 10^8 \text{ liter})}{(1.08 \text{ X } 10^9 \text{ liter})}$$

= 27 million fibers per liter

The associated annual asbestos mass yields are calculated by multiplying the concentrations by the flows. The Knox station mass yield is therefore:

$(1.3 \text{ X } 10^9 \text{ liter})\ (18 \text{ to } 24 \text{ X } 10^6 \text{ fibers/liter}) = 2.4 \text{ to } 3.2 \text{ X } 10^{16}$ fibers/year

Similarly, the Seaview Station asbestos mass yield can be calculated:

$(2.3 \text{ X } 10^8 \text{ liter})\ (11 \text{ to } 16 \text{ X } 10^6 \text{ fibers/liter}) = 2.5 \text{ to } 3.7 \text{ X } 10^{15}$ fibers/year

The urban area asbestos mass yield is calculated by subtraction:

min. value $2.4 \text{ X } 10^{16} - 3.7 \text{ X } 10^{15} = 2.0 \text{ X } 10^{16}$ fibers/yr

max. value $3.2 \text{ X } 10^{16} - 2.5 \text{ X } 10^{15} = 3.0 \text{ X } 10^{16}$ fibers/yr

When these total area yields are divided by the appropriate areas above the monitoring stations, the unit area asbestos mass yields are determined. The urban area is 909 acres, so the unit area asbestos mass yield is expected to be 2.2 to 3.3 X 10^{15} fibers per acre per year.

Street Surface Asbestos Fiber Loadings, Accumulation Rates, and Fugitive Contributions to the Atmosphere

Table 8-2 summarizes the characteristics of street surface particulate asbestos fibers. About 2/3 of all street surface particulate samples collected during both years were analyzed for asbestos using the screening procedure. About 80 percent of these samples had detectable asbestos fiber concentrations, with the average weighted concentration equal to approximately three hundred million asbestos fibers per gram of total solids. Again, almost all of the asbestos fibers observed were chrysotile, with only about 3 percent being amphibole asbestos. The fiber sizes and unit fiber weights were very similar to those observed in urban runoff.

Table 8-3 summarizes the distribution of the asbestos fibers among the different street surface particle sizes analyzed. Most of the asbestos was associated with street surface particles in the size range of 100 to 600 microns. It was noted that there was no appreciable difference in asbestos fiber sizes for different particle sizes. The asbestos fibers appear to be attached or associated with the larger particles and are fairly consistent in their concentrations. Most of the observed fibers, however, were in the middle size ranges, with fewer fibers observed in the very small or the very large particle size ranges.

Street surface loading densities, deposition and accumulation rates, and fugitive dust losses were calculated based upon the observed average concentration of three hundred million asbestos fibers per gram.

Table 8-4 summarizes the loading accumulation rates and fugitive losses of asbestos fibers for the three test areas during the first year and for the combined study area during the second year. The shapes of these accumulation curves are virtually identical to the corresponding curves for total solids. Many more detailed and expensive TEM/SAED analyses would be needed to calculate the unique shapes of the curves for asbestos. However, because of the relatively consistent asbestos concentrations for the different total solids particle sizes and for the different time periods, the values reported here are probably reasonable.

The first accumulation rate value shown in each column (i.e., the value for 0 to 1 day) is the highest accumulation rate and is assumed to be equal to the deposition rate. The asbestos fiber deposition rate is about 5 to 10 x 10^{12} asbestos fibers per curb mile per day. The accumulation rate is initially constant immediately after a significant rain or street cleaning. However, the accumulation rate then decreases because of fugitive dust losses from the street surface to the air (due to automobile and wind turbulence). The difference between the initial deposition rate and the following accumulation rates equals the amount which is lost to the air (shown as a fugitive asbestos loss). This fugitive loss is very small for the first few

TABLE 8-2. CHARACTERISTICS OF STREET SURFACE PARTICULATE ASBESTOS FIBERS

Characteristics and units	Castro Valley Street Dirt
Percentage of collected samples analyzed (42 composite samples analyzed using screening procedure and 5 composite samples analyzed using complete TEM/SAED procedure).	67%
Percentage of samples having detectable asbestos fiber concentrations (>10x10^6 fibers/gram)	81%
Weighted average asbestos fiber concentration (x10^6 fibers/gram)	300
Range of observed asbestos fiber concentrations (x10^6 fibers/gram)	<1 1300
Percentage of total observed asbestos fibers that were Chrysotile asbestos	97%
Percentage of total observed asbestos fibers that were Amphibole asbestos	3%
Asbestos weight concentration (µg asbestos/g total solids)	18
Median Chrysotile particle length (microns)	1.0
Median Chrysotile particle width (microns)	0.07
Median Chrysotile particle aspect (length/width ratio)	19
Unit fiber weights (10^6 fibers/µg) (average and range)	46(12 81)

TABLE 8-3. ASBESTOS FIBER CONCENTRATIONS AND DISTRIBUTION FOR DIFFERENT TOTAL SOLIDS SIZES FOR STREET DIRT SAMPLES.

Total solids particle size (microns)	Asbestos fiber concentration (10^6 fibers/gram total solids)	Asbestos distribution (% of total asbestos fibers in size range)
>6370	100	2
2000 6370	300	15
850 2000	200	14
600 850	300	9
250 600	300	24
106 250	400	26
45 106	200	9
<45	100	1
Total, or weighted average	300	100

TABLE 8-4. CASTRO VALLEY LOADING, DEPOSITION, ACCUMULATION AND FUGITIVE LOSS VALUES FOR ASBESTOS[1]

Days after significant rain or street cleaning	First Year Lower Area loading value (2)	First Year Lower Area accum. rate (3)	First Year Lower Area fugitive loss (4)	First Year Middle Area loading value (2)	First Year Middle Area accum. rate (3)	First Year Middle Area fugitive loss (4)	First Year Upper Area loading value (2)	First Year Upper Area accum. rate (3)	First Year Upper Area fugitive loss (4)	Second Year Complete Area loading value (2)	Second Year Complete Area accum. rate (3)	Second Year Complete Area fugitive loss (4)
0	90	--	0	60	--	0	30	--	0	40	--	0
1	100	10	4	70	9	3	40	4	1	40	5	1
3	110	6	7	80	6	6	40	3	2	50	4	1
5	110	3	8	90	3	6	40	2	2	60	4	2
7	120	2	8	90	3	6	50	2	2	60	3	2
10	120	2	9	100	3	6	50	2	3	70	2	3
20	130	1	9	130	3	7	70	1	3	90	2	4
30	130	<1	10	150	2	8	70	1	3	100	1	4
55	140	<1	10	160	<1	9	80	<1	4	110	1	4
75										120	<1	5
110										130	<1	5

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[1] These values were calculated based on an average asbestos concentration of 300×10^6 asbestos fibers/gram total solids, and the appropriate total solids values.

[2] Loading value units are 10^{12} asbestos fibers/curb-mile.

[3] Accumulate rate units are 10^{12} asbestos fibers/curb-mile/day.

[4] Fugitive asbestos losses are expressed in 10^{12} asbestos fibers/curb-mile/day.

days after a major storm or a thorough street cleaning. However, it could be very large, if several months passed with no street cleaning or significant rains.

Table 8-5 summarizes some of these deposition and fugitive asbestos losses. This table presents the calculated street deposition rates from all sources and from vehicles only, and then compares these values to the fugitive losses from the streets. These fugitive losses could have significant effects at relatively large distances downwind, due to the small size and slow settling of these particles (described later in this section). The total deposition of asbestos fibers on the streets was found to be approximately three times the value presented by Jacko and Du Charme (1973) in their detailed study of asbestos contributions from autos and trucks (i.e., brake and clutch linings). For a typical year, the total street surface asbestos fugitive loss in the basin equals about 2/3 of the total basin street surface asbestos deposition. The "direct" airborne vehicle asbestos loss is approximately 1.0 microgram per vehicle-mile, which is directly emitted to the air during brake and clutch use (as reported by Jacko and Du Charme, 1973). When the fraction of the asbestos fibers that are "dropped out" onto the road surface during normal vehicle use and resuspended by winds is added to this value, the total increases to approximately 17 micrograms per vehicle-mile (or about 60 percent of the total vehicle-related asbestos emissions. The remaining 40 percent probably still affects urban runoff quality, because it could be resuspended and settle on adjacent areas and later be washed off by rains. Approximately 40 percent of the annual fugitive losses of asbestos from the street surface are due to vehicle brake and clutch wear. The remaining losses are associated with many different asbestos sources (as described later in this section).

Street Cleaning Effectiveness for Asbestos Control

Initial and residual street surface asbestos loadings, for before and after street cleaning, are shown in Table 8-6. Table 8-7 shows the obtainable initial street surface asbestos loadings for various street cleaning programs. Asbestos was found to be similar to other street surface contaminants in that street cleaner effectiveness is very poor when the streets are quite clean and are cleaned frequently. The productivity (i.e., the rate of removal per unit cleaning effort) was found to increase substantially when the streets are dirty and are cleaned less frequently. The initial street surface loading values are those right before the streets are cleaned (i.e., when the streets are the dirtiest). The residual values are, therefore, the loading values on the street immediately after the streets are cleaned (i.e., when the streets are the cleanest).

The ability of street cleaning to remove asbestos from urban runoff itself is not well known because of the lack of simultaneous studies on street surface loading and urban runoff yield. However, based upon the ratios of annual runoff yields to annual street dirt accumulations of all the constituents and their respective control values for different cleaning programs, it appears that street cleaning may be very effective in controlling asbestos in urban runoff. It is estimated that weekly street cleaning may control about 10 percent of the asbestos in urban runoff, while maximum

TABLE 8-5. ANNUAL STREET DEPOSITION AND FUGITIVE LOSSES OF ASBESTOS

Characteristics and units	Value
Annual deposition of asbestos fibers (grams/basin-year)	2100
Unit deposition of asbestos fibers (μg/vehicle-mile)	60
Unit vehicle asbestos deposition, from brake and clutch wear - from Jacko and DuCharme, 1973 (μg/veh-mi)	23
Annual vehicle asbestos deposition (grams/basin-year)	780
Percentage of total annual street surface deposition due to vehicle deposition	40%
Annual fugitive asbestos losses from street surfaces (grams/basin-year)	1400
Annual fugitive asbestos losses from street surfaces (fibers/acre/year)	7.2×10^{13}
Annual fugitive asbestos losses from street surfaces (grams/acre/year)	1.6
Percentage of total basin street surface asbestos deposition lost to air as fugitive loss	70%
Actual airborne vehicle asbestos source (fugitive plus direct loss) (μg/vehicle-mile)	17
Percentage of total vehicle asbestos losses eventually affecting the air	60%
Percentage of annual fugitive losses from street surfaces due to vehicle brake and clutch wear	40%

TABLE 8-6. STREET CLEANING EFFECTIVENESS FOR ASBESTOS FIBERS[1]

Initial asbestos street surface loading ($\times 10^{16}$ fibers/curb-mile)	Residual asbestos street surface loading ($\times 10^{16}$ fibers/curb-mile)
2	3
4	4
6	5
8	6
10	7
12	8
14	9

[1] Calculated, based on total solids performance and an average asbestos concentration of 3×10^8 fibers/gram street dirt.

TABLE 8-7. OBTAINABLE "INITIAL" STREET SURFACE ASBESTOS LOADINGS FOR VARIOUS CLEANING PROGRAMS[1]

Cleaning Program (number of passes per year)	Obtainable Initial[2] Asbestos Street Loadings ($\times 10^{16}$ fibers/curb-mile)
0 (never)	15
4 (quarterly)	14
12 (monthly)	13
24 (every 2 weeks)	12
52 (weekly)	9
104 (2x weekly)	6
156 (3x weekly)	5
208 (4x weekly)	4
260 (5x weekly)	4
365 (7x weekly)	4

[1] Calculated, based on total solid performance and an average asbestos concentration of 3×10^8 fibers/grams street dirt.

[2] "Initial" street surface loadings are the loadings immediately before street cleaning (the dirtiest the streets are likely to be).

street cleaning levels (e.g., greater than or equal to four passes per week) may control as much as 50 percent of the asbestos in urban runoff. These high street cleaning effectiveness values are based upon the fact that the annual street surface accumulation of asbestos is about 10 times greater than the total annual urban runoff asbestos yield. It should be recognized that these estimates might be substantially different if more urban runoff samples were analyzed. However, the data assessed for this study does point out a reasonable potential for controlling asbestos in urban runoff by using conventional street cleaning equipment and practices.

Asbestos Fiber Concentrations for Various Source Area Particulates

As described previously, many samples were collected from different source areas in the Castro Valley basin and analyzed for asbestos content. Table 8-8 summarizes the asbestos fiber characteristics observed for these different samples. Asbestos fibers were observed in almost all cases, with average concentrations ranging from 50 to 1000 million asbestos fibers per gram of total solids. Again, almost all of all asbestos fibers observed were chrysotile asbestos--only a few amphibole asbestos fibers observed. The unit fiber weights ranged from about 30 to 140 million fibers per microgram of asbestos, while the representative fiber sizes were quite similar to those found in the urban runoff and street surface particulate samples previously described. The driveway and parking lot samples had the lowest observed asbestos fiber concentrations, while roof top particulates had the highest fiber concentrations. Some of the roofs sampled, however, were covered with asphalt shingles which commonly have imbedded asbestos fibers for reinforcement. In addition, many roofing compounds also contain asbestos fibers. Surprisingly high concentrations of asbestos fibers were observed on the school playground pavement and turf. Vacant lots and creek sediments had much lower observed asbestos concentrations. This indicates that the natural soils may have relatively small asbestos concentrations and that most of the urban runoff asbestos fibers remain in suspension in the water and do not settle out to become trapped in the sediments. The previously reported street surface particulate sample asbestos concentrations were at the approximate mid-point of the range of the asbestos fiber concentrations reported for these other source area particulate samples. Based on these particulate strength observations and the information presented in the literature, the major asbestos source in the Castro Valley watershed is probably automobile activity and possibly roof-top runoff.

TABLE 8-8. CHARACTERISTICS OF OTHER SOURCE AREA PARTICULATE ASBESTOS FIBERS

Characteristics and units	Vacant Lots	Rooftops	Paved School Playground and Turf (1)	Driveways and Parking Lots	Creek Sediments
Percentage of samples having detectable asbestos fiber concentrations (>10x10^6 fibers/gram)	63% (8 samples)	100% (4 samples)	100% (2 samples)	50% (4 samples)	75% (8 samples)
Average asbestos fiber concentration (x10^6 fibers/gram)	100 (2 samples)	1000 (4 samples)	800 (2 samples)	50 (2 samples)	100 (2 samples)
Range of observed asbestos fiber concentrations (x10^6 fibers/gram)	<5 110	300 1900	730 830	<2 55	39 230
Percentage of total observed asbestos fibers that were Chrysotile asbestos	100%	100%	100%	99%	100%
Percentage of total observed asbestos fibers that were Amphibole asbestos	0%	0%	0%	1%	0%
Asbestos weight concentration (µg asbestos/g total solids)	1	20	10	2	1
Median Chrysotile particle length (microns)	1.3	0.9	1.1	1.4	1.0
Median Chrysotile particle width (microns)	0.07	0.07	0.07	0.08	0.07
Median Chrystotile particle aspect (length/width ratio)	19	16	20	21	17
Unit fiber weights (10^6 fibers/µg) (average and range)	81 (70 92)	71(40 100)	63 (52 73)	31 (30 31)	120 (100 140)

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[1] Two other "landscaped areas" (residential lawn and landscaped parks) composite samples were screened. Both were reported to have "light" quantities of asbestos observed by the TEM screening procedure. Neither sample, however, was analyzed using the complete TEM/SAED procedure.

FINDINGS FROM LITERATURE REVIEW

This section consists of an annotated bibliography which describes asbestos fiber characteristics, natural asbestos sources in the Castro Valley test basin, the mining and production of asbestos, the uses of asbestos, the sources of asbestos, the effects of asbestos, and the fate of asbestos.

Asbestos Types, Fiber Sizes and Weights

Asbestos is the name used for the naturally fibrous varieties of the serpentine or amphibole group of minerals. The variety of asbestos most commonly used for domestic, commercial, and industrial purposes is chrysotile, a member of the serpentine group.

Table 8-9 lists some amphibole and serpentine minerals and the asbestiform varieties that are associated with these minerals. Good quality chrysotile fibers are silky, flexible, and have a high tensile strength. If the fibers are long enough, they can be used for spinning and for manufacturing cloth products.

Table 8-10 presents the chemical composition of the major asbestos mineral types (Great Lakes Research Advisory Board, 1975). The predominant oxides in asbestos are silica and magnesium. Iron, calcium, and sodium oxides are also present in most of the asbestos forms, but at much lower concentrations.

The sizes and weights of individual asbestos fibers are very important physical characteristics. Individual asbestos fibers (usually called fibrils) are approximately 0.03 microns in diameter and 0.5 microns (or smaller) in length (Bruckman & Rubino, 1975). The fibrils occur in nature (and in most of our samples) in bundles which make up asbestos fibers. These bundles are typically on the order of one micron in diameter. Because of the wide variety of fiber sizes, it is not possible to make a simple conversion between fiber counts and fiber mass. Most electron microscope analyses for asbestos include counting individual fibrils and enumerating their lengths and diameters. By knowing the specific density of the asbestos fiber types, a calculation can be made to determine the approximate weight of the fibers. In our study of Castro Valley, we found from one to one hundred million fibers per microgram of asbestos. This corresponds to about one thousand to one hundred thousand fibers per nanogram (i.e., 10^{-9} grams). In areas of high occupational exposure, with fiber lengths greater than five microns, one fiber can weigh a nanogram. If each fiber were considered a potential reactive source capable of causing a cancer, then it would be much more important to report survey results in terms of numbers of fibers instead of the weight of fibers present. A few large fibers could radically skew a "rule-of-thumb" conversion factor. This fact has caused various controversies when standards based upon weights of asbestos have been proposed (Bruckman & Rubino, 1975, and Plumlee, 1975). Most of the fibers counted by the electron microscope procedures in the Castro Valley study involved counting individual fibrils and not bundles of fibrils. Fibrils are not visible under optical microscope techniques, and various investigations have attempted to assume a constant number of invisible fibrils per observed fiber for occupational analyses

TABLE 8-9. SELECTED SILICATE MINERALS AND THEIR ASBESTIFORM VARIETIES

Mineral	Asbestiform variety
AMPHIBOLE GROUP	
Anthophyllite: $(Mg,Fe^{+2})_7\ Si_8O_{22}(OH,F)_2$	Anthophyllite asbestos.
Cummingtonite-grunerite: $(Mg,Fe^{+2})_7\ Si_8O_{22}(OH)_2$	Cummingtonite-grunerite asbestos.
Tremolite-actinolite: $Ca_2(Mg,Fe^{+2})_5\ Si_8O_{22}(OH,F)_2$	Tremolite-actinolite asbestos.
Riebeckite: $Na_2Fe_3^{+2}\ Fe_2^{+3}\ Si_8O_{22}(OH,F)_2$	Crocidolite.
SERPENTINE GROUP	
Serpentine: $Mg_6Si_4O_{10}(OH)_8$	Chrysotile.

Source: Campbell, et al. 1977.

TABLE 8-10. CHEMICAL COMPOSITION RANGE OF INDIVIDUAL ASBESTOS MINERALS BY MICROPROBE ANALYSIS

Oxide	Chrysotile	Amosite	Crocidolite	Anthophyllite	Tremolite	Actinolite
SiO_2	38.0-44.0	49.0-53.0	49.0-53.0	56.0-58.0	51.0-60.0	51.0-56.0
UICC	[38.6]	[50.3]	[49.1]	[58.2]		
MgO	40.0-42.0	1.0-7.0	0.0-0.3	28.0-34.0	15.0-26.0	15.0.20.0
UICC	[32]	[11]	[3.6]	[24]		
Fe oxides	0.0-4.0	34.0-44.0	30.0-40.0	3.0-12.0	0.0-15.0	5.0-18.0
UICC	[2.6]	[28]	[27]	[4.4]		
CaO	0.0-1.0	0.0	0.3-2.7	0.0	10.0-13.0	10.0-12.0
UICC	[0.1]	[0.2]	[0.7]	[0.01-0.1]		
Na_2O	0.0-TR	0.0	4.0-8.5	0.0	0.0-TR	0.5-1.5
UICC	[0.001-0.1]	[0.006-0.06]	[7.0]	[0.007-0.07]		

Source: Great Lakes Research Advisory Board, 1975.

Note: UICC (International Union Against Cancer): STANDARD REFERENCE SAMPLES.

(Selikoff, 1972). This proportion may be reasonable for a given industrial situation, if significant data were available to allow one to make extrapolations. However, in environmental studies, the numbers and sizes of asbestos fibers are small, and electron microscope techniques which can count individual fibrils are often necessary. Millette, et al. (1979) reported a fiber-count-to-mass conversion ratio for "natural" samples ranging from one-half billion to five billion fibers per microgram. Millette et al. also described another study (of a cooling tower containing asbestos cement) that reported a conversion factor of five million to one hundred million fibers per microgram. They also reported that fibers from the natural erosion of serpentine rock tend to be shorter and of smaller diameter than those eroded from products containing commercial asbestos. However (as described later in this report), asbestos fibers from automobile clutch and brake wear tend to be quite small.

Naturally-Occurring Geological Sources of Asbestos in the Castro Valley Test Basin

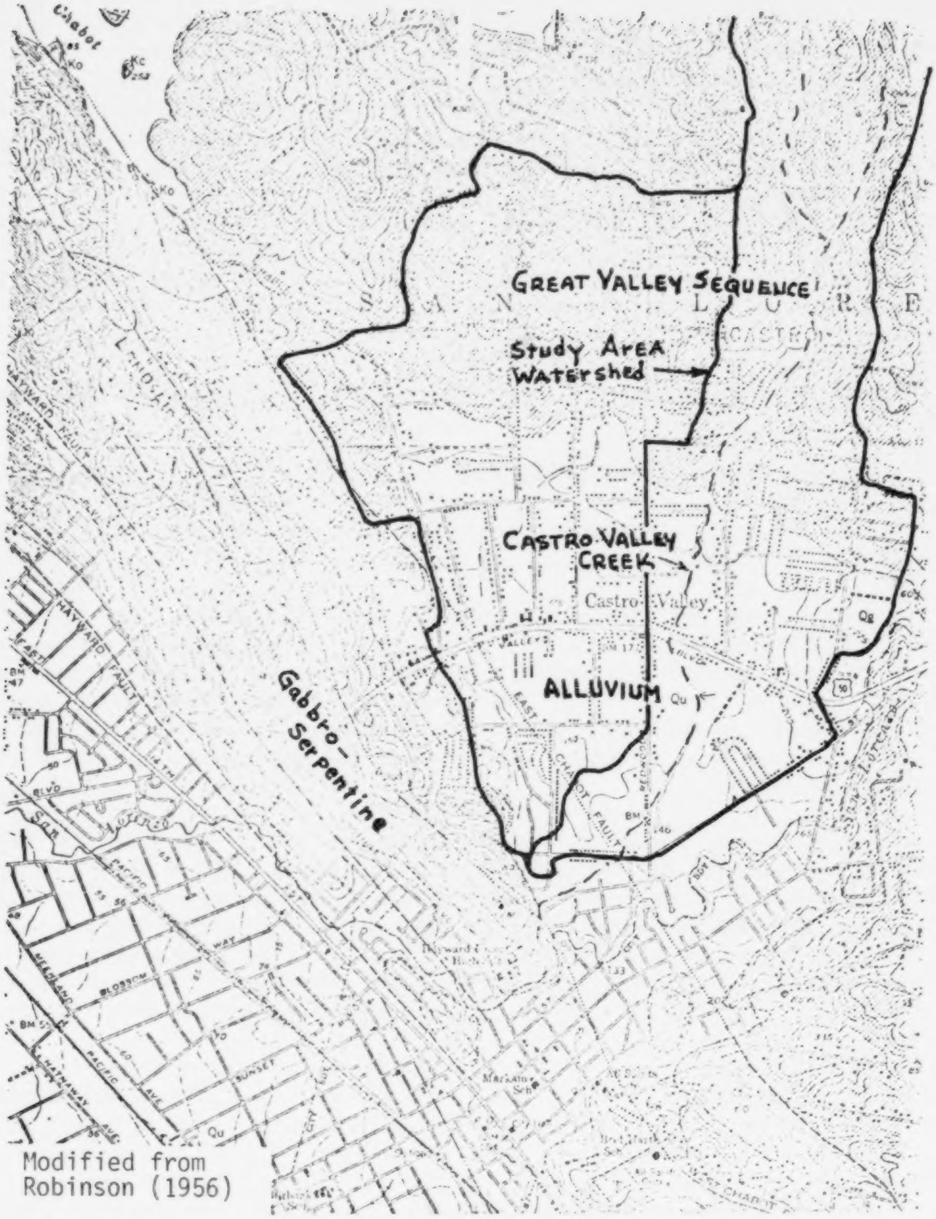
Figure 8-4 is a simplified geological map of the Castro Valley area (adopted from Robinson, 1956). It is unlikely that much asbestos from the local geological formations would be present in urban runoff in the Castro Valley creek watershed.

The study area is underlain by two contrasting deposits as mapped by Robinson (1956) and Perkins (1974): the Great Valley Sequence of Cretaceous age and Holocene alluvial deposits. The Great Valley Sequence underlies those parts of the Castro Valley test area designated as the Rural Area, the Upper Urban Sampling Area, and parts of the Middle Urban Sampling Area. The alluvium underlies the remainder of the Middle Sampling Area and the Lower Urban Sampling Area.

The watershed of the study area originates in the Great Valley Sequence. These strata, as described by Perkins (1974), consist of an alternating sequence of sandstone and mudstone with locally-thick lenses of conglomerate. Compositionally, the sandstones in the watershed area are primarily composed of quartz, feldspar, rock fragments, and biotite. The composition of the sedimentary strata and the apparent source of the debris from the ancestral Sierra Nevada (to the east) suggest a paucity of asbestos-bearing minerals.

The alluvium which underlies portions of the study area was deposited by westerly flowing streams, including Castro Valley Creek, whose headwaters are in the Great Valley Sequence. Accordingly, the composition of the alluvium would be expected to generally reflect the composition of the source rock. Therefore, the alluvium probably does not contain significant amounts of asbestos minerals originating from the bedrock in the watershed of Castro Valley Creek.

Asbestos-containing formations are exposed in the Berkeley Hills west of Castro Valley. The bedrock underlying these hills contains, in part, blocks of gabbro and serpentinite which contain asbestos-bearing minerals such as antigorite and chrysotile. Since most of the exposures of these rock types are on the western slope of the Berkeley Hills and the valleys drain to the


Chabot
GREAT VALLEY SEQUENCE
Study Area Watershed
CASTRO VALLEY CREEK
Castro Valley
ALLUVIUM
Gabbro-Serpentine
HAYWARD FAULT
Modified from Robinson (1956)

Reproduced from best available copy.

FIGURE 8-4. GEOLOGIC DEPOSITS, CASTRO VALLEY, CA.

west (i.e., away from Castro Valley), they do not significantly contribute clastic material to the alluvium in Castro Valley. A relatively small exposure of the undifferentiated gabbro and serpentine has been mapped by Robinson (1956) near the western tip of the study area. Hence, there may be some contribution of asbestos-bearing minerals to the alluvium, but the quantity is believed to be minor and localized.

In conclusion, there are no serpentine outcrops of bedrock in the test area watershed, but the alluvial deposits in the downslope areas of the watershed may contain some greatly-diluted serpentine erosion products mixed with other local erosion products. However, as described in the later subsection on the fate of asbestos fibers, fugitive asbestos fibers from wind erosion can be carried great distances downwind and then redeposited. The San Francisco Bay Area has many serpentine outcrops, some quite close to the test area. In fact, an old asbestos mining operation is located about ten miles from the test area.

Mining and Production of Asbestos

Chrysotile asbestos occurs mainly in veins and veinlets in shear fractures of serpentine (Wiibelt & Smith, 1959). Tremolite and anathophyllite asbestos occur in veins mostly as slip fibers in rocks that are high in magnesium. In some amphibole asbestos deposits, the entire rock is made of fibers with no regular orientation. Tremolite asbestos occurs commonly in California, but is limited to small pockets in narrow veins, whereas massive serpentine outcrops (i.e., the host rocks for chrysotile) are widely distributed throughout California, including the Berkeley Hills and the hills south of the Livermore Valley (Davis, 1950). Chrysotile asbestos is not very common in the serpentines of the Bay Area, but it is found in a few places as veinlets with a width of approximately one eight of an inch (Jenkins, 1951). Serpentines are intrusive into sedimentary and volcanic rocks of the Franciscan group of the upper Jurassic period. The predominant rock in the Franciscan group is a hard, tough, slightly-metamorphosed, greenish-gray sandstone (Jenkins, 1951).

A small amount of short-fiber asbestos was mined from a small deposit in Alameda County near the Contra Costa County line, in the hills east of Fruitvale (i.e., the north half of Section 36, Township 1 south, Range 3 west) in 1915 and 1918. The fiber was mixed with magnesite and used by the John D. Hoff Asbestos Company in manufacturing asbestos stucco, flooring, and steam pipe covering. There has been no production recorded at this mine site since 1918 (Davis, 1950, Wiebelt & Smith, 1959, and Jenkins, 1951).

There is some evidence that asbestos was used in Stone Age pottery. The use of asbestos during the last eighty years has increased by about one thousand fold--this was more than ten times the increase in the use of petroleum products during the same time period. World-wide use of asbestos is currently greater than three million tons annually (Buchanan, 1979). Most of the asbestos used in the United States comes from Canada, with South African supplies being a distant second. However, South Africa is the sole U.S. source for crocidolite (blue) asbestos and amosite asbestos (Shride 1973). Chrysotile asbestos constitues more than 90 percent of the world asbestos use, and

Canada is the principal supplier. Even though California was extensively prospected and did yield small quantities of asbestos after 1882, no large-scale mining operations were conducted until 1962, when a plant with a capacity of 2500 tons of ore per day began operation on a deposit near Copperopolis (in Calaveras County). Short fiber deposits in eastern San Benito County and western Fresno County (northwest of Coalinga) began to be mined in 1963. California then became the principal asbestos producing state in the U.S. and currently furnishes more than 75,000 tons of chrysotile fibers annually (Shride, 1973). The total U.S. production of asbestos in 1979 and 1978 was approximately 100,000 tons per year. This was equal to about twenty-eight million dollars. U.S. production of asbestos in 1979 came from California, Vermont, and Arizona, in that order. The consumption of asbestos in 1979 was approximately 650,00 tons (more than six times domestic production). Approximately 600,0000 tons was imported from Canada; approximately 18,500 tons came from the Republic of South Africa (plus some 570 tons of amosite) (Derricott, 1979).

Uses and Alternatives of Asbestos

Asbestos is used in more than 3000 different products in the United States. In 1976, roofing products accounted for 35 percent of the annual use of asbestos (and was the largest user). Asbestos-cement pipe was next, with 19 percent. This was followed by flooring products, with 16 percent. Three percent was for asbestos-cement sheets. Products used in the construction industry accounted for about three fourths of the asbestos consumed in 1976. Other major asbestos-using end products were friction materials (9 percent), paper (4 percent), coatings and compounds, packing and gaskets, and plastic (3 percent each), and textiles and thermal insulation (1 percent) (Clifton, 1978).

Table 8-11 presents information from the Asbestos Information Association of North America, reported by SRI (1978). It describes some of the major asbestos products and their end uses. Many products contain asbestos, some without the knowledge of most users. There is a great difference in various products' abilities to release asbestos fibers during normal product use. This depends upon the ease with which the fibers can be dislodged. Almost all of the asbestos fibers used in manufacturing U.S.-made products become tightly bound and undergo little abrasion or wear before being discarded. This is true, for example, of asbestos-cement products, shingles, and floor tiles. Brake and clutch linings however, are subject to great friction and wear, with considerable fiber release. The effect of brake lining wear as an asbestos source is described in a following subsection.

About one to three percent of the asbestos used in the U.S. is as fibrous asbestos, including asbestos cloth, paper, and sprayed-on fireproofing materials. The asbestos fibers in these products are not tightly-bound, and fiber releases occur during the application, the useful life, and the subsequent removal of the material. Asbestos may also occur as a contaminant in other common products (most noteably talc) and can therefore be a potential source for inadvertent exposure (National Research Council, 1971).

TABLE 8-11. SELECTED ASBESTOS PRODUCTS AND THEIR END USES

Floor Tile	Gaskets and Packings	Friction Products	Paints, Coatings and Sealants	Asbestos-Reinforced Plastics	Asbestos Cement Pipe
Office floors Commercial floors Residential floors	Valve components Flange Components Pump components Tank sealing components	Clutch/transmission components Brake components Industrial friction materials	Automotive/Truck body coatings Roof coatings and patching compounds	Electric motor components Molded product compounds for high-strength/weight uses	Chemical process piping Water supply piping Conduits for electric wires

Asbestos Textiles	Asbestos Paper	Asbestos Cement Sheet
Packing components Gasket components Roofing materials Commercial/Industrial dryer felts Heat/fire protective clothing Clutch/transmission components Electrical wire and pipe insulation Theater curtains and fireproof draperies	Gas vapor ducts for corrosive compounds Fireproof absorbent papers Table pads and heat protective mats Heat/fire protection components Molten glass handling equipment Insulation products Gasket components Underlayment for sheet flooring Electric wire insulation Filters for beverages Appliance insulation Roofing materials	Hoods, vents for corrosive chemicals Chemical tanks and vessel manufacturing Portable construction buildings Electrical switchboards and components Residential building materials Molten metal handling equipment Industrial building materials Fire protection Insulation products Small appliance components Electric motor components Laboratory furniture Cooling tower components

Source: Asbestos Information Association/North America, reported by SRI, 1978.

Table 8-12 presents information supplied by the Asbestos Information Committee, as reported by Derricott (1979). It shows the types of asbestos fibers and the approximate asbestos content in different building products manufactured in the United Kingdom. Fire insulating materials contain mostly amosite asbestos. All chrysotile fibers are used for reinforcement of other products. These products are reported to contain significant quantities of asbestos.

As noted above, much asbestos is used in asbestos-cement pipe. In 1938 there were 40,000 miles of asbestos-cement pipe in service, while in 1974 about 1,500,000 miles of asbestos-cement pipe were in service, world-wide. About 200,000 miles of asbestos-cement pipe are in use in the United States (Olson, 1974). Much concern has been raised about the possible health effects of using asbestos-cement pipe for transporting drinking water. As noted later in this discussion, the safety of using asbestos-cement pipe varies greatly on the chemical properties of the water and its ability to corrode the cement (which then leads to the release of asbestos fibers). It should be noted that many waters are not capable of eroding the asbestos-cement. Careless handling of the pipe and certain tapping and construction practices can also lead to the release of asbestos fibers.

Asbestos-cement sheets are also widely used as building siding and as bulkheads in coastal areas (especially on the southern Atlantic seaboard). These asbestos-cement sheets are subject to wave action and repeated drying and wetting. Degradation of the cement can follow, leading to the release of asbestos fibers to the water.

In many products, the use of asbestos is critical, especially in friction materials and electrical insulation, where its resistance to moisture, flexure, fatigue, and abrasion and its ability to absorb resins are as important as its heat and flame resistance. Asbestos is also important as an abrasion-resistant and corrosion-resistant binder and a reinforcing material in products made of rubber or plastic. Similarly, asbestos is also mixed with lubricants and other compounds used in packing materials and gaskets, where an inert filler material is required. When it is laminated into paper or used in textiles, these products are made less vulnerable to fecal bacteria, or vermine attacks and are usually not affected by wetting and drying (Shride, 1973).

For most applications of asbestos, alternatives could be substituted (e.g., using a glass or ceramic fiber). However, alternative fibers are not always as effective in meeting specific product requirements without creating potential health hazards. The most resistance to using alternative fibers derives from the much higher cost of most of the alternatives. The most difficult industrial asbestos products to substitute are insulation materials subject to loading, flexure, or corrosive environments; specialized bearings; and a few textile applications. Those products where asbestos is used as a filler for economic reasons usually have the asbestos tied with a binder, with resultant minimal asbestos fiber exposure (Campbell, et al., 1977). Therefore, finding suitable alternatives for asbestos fibers has been very difficult for both economic and technical reasons.

TABLE 8-12. AMOUNTS OF ASBESTOS, BY TYPE, CONTAINED IN U.K. MANUFACTURED BUILDING PRODUCTS

Building product	Asbestos Content (%) (approx.)	Asbestos Type
Asbestos-cement building products (except pipes)	12-15	Chrysotile
Fire-resistant insulating boards	25-40	Amosite (with a small percentage of chrysotile in some cases)
Asbestos paper	70-95	Chrysotile
Asbestos millboard	45-98	Chrysotile
Asbestos insulation blocks and pipe sections	55	Amosite
Asbestos-reinforced thermosetting plastics	55	Chrysotile
Asbestos jointings and packings	25-85	Chrysotile
Asbestos textiles	85-100	Chrysotile
Asbestos-cement pipes	12-14	Chrysotile with a small proportion of amosite
Vinyl/asbestos floor tiles	5-7 1/2	Chrysotile

Source: Asbestos Information Committee, reported by Derricott, 1979.

NATURAL ASBESTOS SOURCES

Concentrations of Asbestos in Ambient Air

Many studies have monitored the concentrations of asbestos in the air of U.S. cities. Most of these studies unfortunately, only report the results on the basis of mass and not fiber counts. Table 8-13 is a summary of many such studies reported by SRI (1978) and Suta & Levine (1979). The overall range of observed asbestos fiber concentrations went from less than one to a high of approximately 200 nanograms per cubic meter. Most of the averages were less than 40 nanograms per cubic meter. The U.S. EPA (1978) summarized the distribution of more than 300 asbestos samples collected nationwide. About 90 percent of these samples had concentrations of less than 5 nanograms per cubic meter, while more than 25 percent of the samples had concentrations of less than one nanogram per cubic meter. It was found that asbestos occurs in almost all urban areas, mostly as the chrysotile variety. These data covered more than 50 United States cities during 1969 and 1970 and were based on quarterly composite samples and 24-hour composite samples. Of the two cities with the highest ambient asbestos concentrations, one had a major shipyard, the other had four brake manufacturing facilities. These industrial sources may have been responsible for the high observed concentrations (U.S. EPA 1978). The EPA also found that the atmospheric concentrations of asbestos for 24-hour averages in metropolitan areas usually were less than 5 nanograms per cubic meter, but can range up to 20 nanograms per cubic meter. Values up to 50 nanograms per cubic meter can be found during daylight hours in locations where construction activities (especially spraying asbestos insulation) and traffic may be contributing sources.

Murchio, et al. (1973) monitored asbestos fiber concentrations in various locations in southern California and in the Bay Area. They found that the chrysotile asbestos fiber concentrations at all the locations were low-- in the range of less than one to a maximum of about 10 fibers per liter. They found that the chrysotile asbestos concentrations monitored in 1980 in Los Angeles did not differ significantly from the average of the concentrations in the ambient air sampled in the San Francisco Bay Area, other California cities, and on top of White Mountain in California. These ambient concentrations were found to be approximately one fiber per liter. About 50 percent of the fibers in these air samples were single fibrils, and measured approximately 0.03 microns in diameter. They also monitored the concentration of glass and unidentified fibers in the Los Angeles and the San Francisco Bay Area. These concentrations were also found to be low (i.e., approximately the same order of magnitude as the chrysotile asbestos fiber concentrations). Amphibole asbestos fibers in the air were estimated at Los Angeles freeway monitoring sites and were found to be approximately the same order of magnitude as the chrysotile asbestos fiber concentrations.

Concentrations of Asbestos in Natural Waters

Stewart, et al. (1976) collected many water samples from natural sites in Montana, California, and along the Connecticut River. Observed asbestos concentrations were as high as 10^8 fibers per liter and were subject to seasonal variations. The observed fibers were usually below 5 microns in

TABLE 8-13. ATMOSPHERIC ASBESTOS CONCENTRATIONS IN SOME U.S. URBAN AREAS (Nanograms/m^3)

	Average	Range
Berkeley, CA	6.8	2.1-12
Boston, MA	5.0	
Chicago, IL	24	9.5-200
Dayton, OH	6	0.4-11
Frankfort, KY	0.09	0.02-0.15
Houston, TX	5	4-6
Los Angeles (freeway)	27	
Los Angeles (control)	43	
New York City, NY	13.2	8.2-41
Manhattan, NY	30	8-65
Brooklyn, NY	19	6-39
Bronx, NY	12	2-25
Queens, NY	9	3-18
Staten Island, NY	8	5-14
Pittsburgh, PA	4	2-8
Philadelphia, PA	70	45-100
Port Allegany, PA	15	10-20
Ridgewood, PA	20	15
San Francisco, Ca	25	8.7-68
Washington, DC	21	1.6-40

Source: Many studies, summarized by SRI 1978 and Suta and Levine 1979.

length. It was noted that asbestos fibers frequently could not be found during low-flow conditions at locations where they had been detected during high-flow conditions. They also found that the larger asbestos fibers settled in lakes and reservoirs, thereby reducing the mass of the asbestiform minerals per unit volume (although the number of fibers per unit volume did not always decrease). This was because a single large particle can raise the mass concentration significantly and still have little effect on the number of fibers per liter. Samples were also collected from sites in the Hiwassee River Valley in Georgia and North Carolina; the Little Tennessee Valley in Georgia, North Carolina, and Tennessee; and the Chattanooga-Savannah River Valleys in Georgia and South Carolina. The river samples were found to contain no detectable asbestos. Cunningham and Pontefract (1973) found that melted snow had considerably higher concentrations of asbestos fibers than river water.

A considerable amount of data on asbestos fiber concentrations has been collected for the Great Lakes. The U.S. EPA (1976) reported that, during normal lake conditions, fiber concentrations ranged from 20 to 75 million fibers per liter and about 5 to 30 micrograms per liter. During storm conditions, however, amphibole fiber concentrations as high as 600 million fibers per liter were observed. The Great Lakes Research Advisory Board (1975) reported that the background levels of asbestos fibers in the Great Lakes varied widely, from less than 1 to approximately 10 million fibers per liter. Kay (1974) analyzed asbestos fibers from Thunder Bay (on Lake Superior) and found that the median particle size by number was just over 0.1 micron in diameter, whereas the median particle size by mass was about 0.3 micron in diameter. The concentration of the fibers was approximately 800,000 fibers per liter, and the estimated mass concentration was approximately 0.0002 micrograms per liter. The measured Castro Valley Creek concentrations of 15 to 300 million fibers per liter were on the high end of the range observed in the Great Lakes and in most natural waters studied elsewhere. The sizes of the particles observed in Castro Valley Creek were about the same as observed at other natural sites.

Concentrations of Asbestos in Soils

Several varieties of asbestos (and rocks containing asbestos fibers) occur as out-crops or lie just below the surface of the earth throughout the world. Asbestos fibers from these formations can become airborne during road building, construction, and tilling of the soil, as well as landslides, erosion, and weathering. The weathered products from these outcrops can also contribute asbestos to the surrounding soil. Other materials which contain asbestos fibers (e.g., talc) also occur extensively in the United States in friable forms. Polarized-light examinations of asbestos fibers in glacial ice (which are currently being conducted) will permit researchers to determine the relative contributions of natural and industrial sources of asbestos fibers (National Research Council, 1971). There are several documented instances in Northern Europe (Selikoff, 1972, and Burikov & Michailova, 1970) where local agricultural soils contained enough asbestos fibers to cause health problems for the local farming population.

Concentrations of Asbestos in Rain Water

In their efforts to determine sources and pathways of asbestos pollution affecting Lake Michigan, Hallenbeck, et al. (1977) collected rain water samples in downtown Chicago and at two suburban locations. None of the suburban rain water samples contained levels of chrysotile contamination significantly above laboratory contamination levels. However, the Chicago rain water samples (which were collected near a busy intersection and building construction) had concentrations ranging from 100,000 to 20,000,000 chrysotile fibers per liter. Corresponding mass concentrations ranged from approximately 2 to 120 nanograms of chrysotile asbestos per liter of rain water. It was concluded that precipitation serves to scavenge airborne chrysotile asbestos, and that this could result in the contamination of surface waters.

MAN-MADE ASBESTOS SOURCES

Industrial Asbestos Sources

Because so many different products utilize asbestos, the fiber characteristics from industrial sources also differ considerably. Table 8-14 (from Suta & Levine, 1979) summarizes the quantities of asbestos affecting different receiving environments (for 1974). This table shows that the consumption or ultimate disposal of asbestos products accounts for most of the asbestos releases. In addition, practically all of this material is disposed of in landfills. Emissions to the air from asbestos processing, manufacturing, and consumption total more than 2000 tons per year. Most of this is from process emissions, with about 25 percent of the total emissions to the air occurring as fugitive losses from land disposal. About 170 tons of asbestos per year are discharged into water, mostly during manufacturing processes. These estimates of asbestos disposal and emissions do not include the asbestos in the waste streams of other mineral processing facilities. A notable example would be the asbestos emissions from iron ore processing, which has created substantial problems in Lake Superior and various drinking water supplies. California, Vermont, Arizona, and North Carolina are the principal states where the asbestos is mined. Fibers are emitted during the removal of overburden and the preparation of the ore body for open-pit mining. Additional fiber releases occur from drilling and ore breaking activities and from waste piles of mills and mines. This is a particular problem where waste piles are exposed to the wind and to disturbance by bulldozing. Fibers are also emitted during ore drying, crushing, grinding, and screening operations. Where dust collecting and air cleaning devices are used, disposal of the dust in landfills may not totally contain the fibers (National Research Council, 1971).

Emissions of asbestos fibers to the atmosphere can occur during transportation of asbestos-bearing materials and ore. Asbestos ore sometimes is moved from the mine to the mill in open trucks, while milled asbestos fiber is usually shipped in bags. If the bags are reused, they can become a source of fibers. If the bags are broken, asbestos fibers can be lost during handling. Similar emissions occur during the shipment of products. Transporting asbestos-bearing solid wastes in open vehicles through urban areas may be an important emission source (National Research Council, 1971).

TABLE 8-14. ASBESTOS WASTE DISPOSAL AND EMISSIONS FROM PRODUCTION, MANUFACTURING, AND CONSUMPTION (1974, U.S. TONS) OF ASBESTOS MATERIALS[5]

	Disposal to Land	Emissions to Air			Emissions to water	Total Emissions and disposals
		from process	from disposal[1]	total		
Production						
Mining	6,900	410	--	410	17	7,400
Milling	14,000	1100	--	1100	17	15,000
Subtotal	21,000	1600	--	1600	33	22,000
Manufacturing	20,000	160	420	580	110	21,000
Consumption[4]	540,000	67	100[2]	170	28	540,000
Total	590,000	1800	520	2300	170	590,000[3]
Percentage of total	100%	0.3%	0.1%	0.4%	<0.1%	--

Source: Suta and Levine, 1979.

[1] These emissions are losses from land disposal, as fugitive dust losses.

[2] Includes about 17 tons emitted from incineration of asbestos containing solid wastes.

[3] This compares to a total U.S. consumption of asbestos in 1974 of 840,000 tons.

[4] Consumption is mostly ultimate disposal of products after their useful life.

[5] These losses do not include emissions of asbestos as a waste product from non-asbestos industries (such as iron-ore processing).

Bruckman and Rubino (1975) estimated the asbestos air pollutant emissions in the state of Connecticut. They reported that nearly 200 tons per year of asbestos fibers could be lost from the four friction-material manufacturing facilities in that state (in 1972). Asbestos-cement, floor tile, paper, textile, and miscellaneous asbestos manufacturing facilities (totalling about 40 facilities) added up to contribute an air emission load of about 5 tons per year for Connecticut. They recognized that demolition operations from about 2500 different demolition sites per year could also be important sources of atmospheric asbestos, but these were not quantified. Emissions from asbestos mining, milling, and processing and various consumptive uses of asbestos have all been estimated by Anderson (1973). However, Anderson's emission factor estimates were based on engineering procedures and did not include any source sampling. Hence, they are of limited use in quantifying asbestos emissions. For example, his factors for mining and milling ranged from 2 to 100 pounds of asbestos fibers lost to the atmosphere per ton of asbestos produced. His estimates for asbestos fiber losses to the air during asbestos processing ranged from 1 to 40 pounds of fiber lost per ton processed. For consumptive uses of asbestos (including brake lining wear, steel fire proofing, and insulating cement), Anderson estimated asbestos losses from 10 to 25 pounds of fiber lost to the air per ton of asbestos supplied. Murchio et al. (1973) monitored high concentrations of chrysotile asbestos in a Bay Area ambient air sample that was taken downwind from an asbestos source (i.e., an open dump in the East Bay which at the time was being used by a manufacturer of asbestos products). The observed concentration was about 240 fibers per liter, but was based upon a relatively small sample of air.

Public water supplies in various locations of the country have been found to be contaminated by asbestos fibers that were thought to be caused by erosion of asbestos waste piles into the water supply river (Millette, et al. 1979). The cities were Atlanta, Philadelphia, and Danville (Kentucky). It was thought that storm conditions caused infrequent but substantial amounts of asbestos fibers to be present in the runoff water, samples of which contained asbestos fiber concentrations above 10 million fibers per liter. The distribution of asbestos dump sites in the U.S. and the possibility of the fibers from the dump sites reaching public water supplies has not been determined.

The best known case of industrial asbestos fibers affecting public water supplies resulted from the Reserve Mining Company's operations at Silver Bay on Lake Superior. This operation processed iron ore and discharged large quantities of asbestos fibers (from the ore) into Lake Superior. This source could be specifically identified, because Cummingtonite (the asbestos type which occurs as a natural contaminant in Reserve's taconite ore deposits) differs from other asbestiform fibers (Great Lakes Research Advisory Board, 1975). Reserve's samples collected from Duluth (located about 50 miles away) from 1939-40 and 1949-50 (before mining) contained trace amounts of asbestos fibers, but all samples studied from 1964-65 (after mining) contained much larger amounts of asbestos (averaging about 30 percent of the total inorganic solids) (Levy, et al., 1966). It should be noted that the Reserve mining operations have subsequently been terminated because of these asbestos problems and other waste disposal problems and that Duluth currently filters its drinking water to bring the asbestos fiber count within acceptable limits.

The Reserve Mining Company operations did not entail asbestos processing and therefore were not typically included under asbestos industry waste discharges. Because of the ubiquitous nature of asbestos in common minerals and soil, discharges of asbestos fibers may be common for many mining and ore processing waste activities.

The concentrations of asbestos fibers emitted from asbestos product manufacturing facilities may range from below the detection limits of electron microscopy to values greater than 10^{12} fibers per liter (Stewart, et al., 1976). The concentrations of fibers greater than 5 microns in length can be in excess of 10^{11} fibers per liter in certain cases. Stewart et al. concluded that, of all the industrial locations they sampled, plants that manufactured asbestos paper presented the greatest potential for contamination of surface waters. They found very high levels of asbestos in the final effluent (i.e., 10^{10} to 10^{12} fibers per liter, maximum), with total volumes of discharge ranging from 1/4 to 1 million gallons per day. They found asbestos concentrations in the final effluent of asbestos-cement pipe, asbestos tile, and asbestos textile manufacturing plants to be on the order of 10^{6} to 10^{7} fibers per liter. Asbestos-cement sheet manufacturing facilities had asbestos concentrations in their final effluent of 10^{7} to 10^{10} fibers per liter, while friction material manufacturing facilities had asbestos fiber concentrations of 10^{9} to 10^{10} fibers per liter.

Millette, et al. (1979) noted that industrial discharges in Missouri contained more than 10^{9} fibers per liter, while an industrial discharge in Ohio was found to be under 10^{6} fibers per liter after treatment by settling ponds. It was stated that there are no data to show with certainty that these discharged fibers make their way into public water supplies.

As noted above, the most important asbestos discharge may well be associated with the disposal of asbestos-bearing solid wastes. These wastes come from mining and milling, product manufacture, and the disposal of asbestos-containing products after their useful life. Many such waste materials are disposed of without regard to their potential as emission sources. Common methods of disposal often involve combining asbestos-containing wastes with other municipal wastes in open dumps, which can create long-term emission problems (National Research Council, 1971). Suta & Levine (1979) state that almost 40 percent of all asbestos product manufacturers have some type of resource recovery units to recycle asbestos fibers from their waste streams. An estimated 37 percent of the facilities surveyed in 1974 discarded process waste material in special asbestos dumps (probably just open piles) while 13 percent of the product manufacturing facilities disposed of asbestos waste in landfills. It was estimated that 5 percent sell their waste, 3 percent store their wastes, and 2 percent of the manufacturing facilities store their asbestos wastes as a slurry for some unspecified final disposal. It is obvious that much more effort should be directed toward evaluating solid waste disposal practices of asbestos wastes and developing appropriate solid waste disposal practices.

Construction and Demolition Asbestos Sources

Asbestos fiber sampling in New York City showed that Manhattan had higher levels of asbestos than other borroughs, most likely because of the use of asbestos in the construction of steel-frame buildings. From about 1960 to 1972, it was common practice to spray fire proofing material containing 10 to 30 percent asbestos onto girders, spandrels, and decking of highrise buildings. Often inadequate precautions were taken to contain the oversprayed material, and extensive "snow falls" of asbestos-containing material took place over broad areas of Manhattan. This was of such obvious concern that New York City banned the spraying of asbestos fire-proofing in 1972 (Selikoff 1972). Prior to the implementation of this ban, data were collected in lower Manhattan in the vicinity of buildings under construction. Selikoff (1972) reported that, on the two days of sampling, concentrations from 15 to 80 nanograms of asbestos per cubic meter were observed. Suta and Levine (1979) reported a study that measured concentrations of asbestos as high as 60 nanograms per cubic meter at a distance of 1/8 to 1/4 mile from a spray fire-proofing operation. The concentrations decreased to about 18 nanograms per cubic meter at about 1/2 to 1 mile from the spray site. The overall range was reported to be 3.5 to almost 400 nanograms per cubic meter near these construction sources.

The demolition of buildings containing asbestos products, especially insulation, can also result in the release of large quantities of asbestos into the air. Bruckman and Rubino (1975) feel that the annual tonnage of asbestos fibers lost due to demolition operations would significantly increase the currently quantifiable asbestos emissions from conventional sources. The National Research Council (1971) also states that the demolition of industrial and commercial buildings that have been fire proofed with asbestos-containing materials will be an emission source in the future requiring special control measures. Usually single family residential structures contain only small amounts of asbestos insulation and would not create nearly the same problems during demolition as industrial or commercial facility demolition.

Vehicle Asbestos Sources

The major asbestos losses from vehicle use are brake and clutch wear. Jacko and Du Charme (1973) conducted extensive tests to determine the emissions of asbestos fibers from normal braking operations. They constructed special covers around the vehicle brake drums and monitored the quantities of asbestos retained in the brake drum mechanism, the amount of asbestos that fell out onto the road, and the quantity of asbestos that was directly emitted into the atmosphere. The asbestos retained in the brake mechanism would be available for exposure to automobile mechanics during brake and tire maintenance operations. The calculated total asbestos emissions from normal brake operations were about 30 micrograms of asbestos fibers per vehicle mile. Most of this material (23 micrograms per vehicle mile) would drop out directly onto the road surface with about 4 micrograms per vehicle miles retained in the brake mechanism. A little over 1 microgram per vehicle mile would be directly emitted to the atmosphere. Much of the material that is deposited onto the roadway can be re-suspended into the air as a fugitive dust loss due to automobile induced turbulence in normal winds. This would increase this airborne emission factor from a little over one microgram per vehicle mile (as reported by Jacko and Du Charme) to about 17 micrograms per vehicle mile. This would be the ultimate atmospheric emissions of asbestos from vehicle operations assuming that significant rains or street cleaning occurs every two weeks. If the street cleaning or rain frequency was more frequent the actual losses to the atmosphere would be much smaller and would approach the one microgram per curb mile value. Simiarly, if the streets were subjected to longer periods of dry weather and very infrequent street cleaning, the total vehicle atmospheric emission losses could approach a total of about 30 micrograms per vehicle mile. The fiber sizes monitored by Jacko and Du Charme ranged in length from 0.05 to 100 microns in length and from 0.02 to 10 microns in width.

In another study Alste, et al. (1976) obtained fresh and worn brake lining material and near freeway atmospheric samples for electron microscopy and electron defraction analyses. They found that the major effect of braking appears to be in separating bunches of fibers and reducing their average length but not in altering their crystal structure. They did not find any evidence that heat generated during braking operations caused gross changes in the crystal structure of the asbestos. Where slight braking took place, the airborne concentration near the freeways was very low and could not be satisfactorily measured. At a location with considerable braking, an estimated 500,000 asbestos fibers per cubic meter were observed with each particle consisting of a small bundle of fibers with maximum linear dimensions of less than 2 microns. They also state that because of the absence of crystal degradation it is difficult to separate fibers associated with braking operations from fibers associated with other sources. They did find that the concentrations of atmospheric asbestos near roadways is very low and supports the assumption that only small fractions of the total asbestos dust formed during braking operations becomes airborne. However, no indication was given for street cleanliness or the frequency of rains or street cleaning for this test.

Murchio et al. (1973) also monitored near freeway air samples for asbestos. Very few of their samples had high concentrations of chrysotile asbestos. The samples were obtained during periods of heavy and fast moving traffic and heavy and slow moving traffic with light wind. The asbestos fibers from these samples are quite different from the asbestos fibers usually found in ambient air. Most of the fiber bundles or fibrils were attached or sticking out of irregular particles 5 to 15 microns in diameter. These particles melted in the high intensity electron beam and could have been rubber particles from the brake linings. They state that many kinds of brake linings contained ground-up recycled rubber tires along with asbestos and other materials. They also state that a source of non-chrysotile asbestos on freeways and ambient air might be from talc, which contains asbestos fibers of the amphibole type (Tremolite) and is used in the maufacturing of rubber tires and some brake linings.

Some studies investigated ambient air asbestos concentrations near toll booths. Murchio et al. (1973) reports of a study that only found low concentrations (about 1 to 2 fibers per liter) of atmospheric asbestos fibers near the toll booth of the San Francisco Bay Bridge. A considerable amount of braking occurred at this location as 11,500 vehicles per hour pass through 17 toll booths and 85 percent of the motor vehicles stop to pay a toll. However, another study reported by Bruckman and Rubino (1975) state that an asbestos sample collected near a toll booth in New York City had 3 to 5 times the asbestos concentrations as normal background levels. Murchio et al. also describes the significant variation in atmospheric asbestos concentrations near freeways for different times of the day. Unfortunately, Murchio did not simultaneously monitor for carbon monoxide or some other conservative pollutant mostly admitted by automobiles that could have been used as a tracer to indicate atmospheric dispersion conditions.

Some of the atmospheric asbestos fibers collected by Murchio near a freeway appeared to be damaged by friction. These could have been emitted during sudden stopping or panic braking on the freeways which would have been relatively rare. Jacko and Du Charme (1973) state that the mechanism by which the organic friction materials used in brakes and clutches can be worn are classified under 5 categories including thermal, abrasive, adhesive, macroshear and fatigue. Thermal, abrasive, and adhesive wear are considered to be the most important mechanisms, with thermal wear predominating above 450° Fahrenheit, and abrasive and adhesive wear predominating below 450° Fahrenheit. Most normal braking operations are below 500° Fahrenheit and only abrasive braking raises brake temperatures above 500 or 600° Fahrenheit. At these higher temperatures the phenolic resin binders gradually pyrolyze, weaken and become brittle allowing the wear to increase rapidly. During normal braking operations the organic constituents pyrolyze or oxidize and are emitted to the air as carbonaceous solid particles or gaseous reaction products. Those asbestos fibers not oxidized are pulverized into small particles and are either trapped in brake or clutch housings, fall to the ground or are emitted to the air. They further state that disk brakes do not trap as many fibers as drum brakes. However, the asbestos during normal braking operations is heated to temperatures high enough to cause some chemical conversion to olivine or forsterite particles. Measurable quantities of asbestos are still lost to the road surface and emitted eventually to the air.

Degradation of Asbestos-Cement Products

Many studies have been concerned with the degradation of asbestos-cement pipe because of the potential for asbestos fiber contamination of drinking water. Many studies have conflicting conclusions concerning the effects of asbestos-cement pipe on water quality. Some of these studies are summarized below.

Millette, et al. (1979) summarized the corrosive effects of certain waters on asbestos-cement pipes. An aggressiveness index was established by the American Water Works Association as a measure of the relationship between water quality and corrosive effects on cement pipe. Waters with aggressive indexes (AI) of less than 10 are classified as highly aggressive. AI indexes between 10 and 12 are moderately aggressive. AI indexes greater than 12 are classified as non-aggressive. Sixteen percent of all U.S. municipal water supplies have highly aggressive waters. Fifty-two percent have moderately aggressive waters. The remaining municipal systems (32 percent) have non-aggressive waters. Their study sampled and analyzed five asbestos-cement pipe systems for a year. Significant numbers of fibers were found in the water from two of the systems which had AI values less than 10. Very few fibers were found in the water samples from three systems with AI values greater than 12. Their findings show that as many as 70 percent of all U.S. water supply utilities are potentially capable of eroding asbestos-cement type 1 pipe. The water supplies with very aggressive waters may have significant corrosion problems with any type of pipe used. If asbestos-cement pipe is used in water supply utilities with very aggressive waters the consumers may be exposed to significant concentrations of asbestos (Millette et al. 1979). This report also cited an example occurring in Florida where asbestos-cement pipe from a well source with non-aggressive waters had high concentrations of asbestos fibers in the distribution system. High hydrogen sulfide concentrations in the water were causing corrosion of the pipe. The Florida town is planning to treat the water for hydrogen sulfide removal before it flows into the asbestos-cement pipe distribution system.

In another study, Machemehl et al. (1978) reported the severe deterioration of asbestos-cement bulk heads along the south Atlantic sea coast. The asbestos-cement was severely corroded through the aggressive action of dissolved carbon dioxide in the water on the calcium carbonate in the cement material. Calcium bi-carbonate was formed and leached out of the structure into solution. This caused a decrease in material density and increased its porosity. It was concluded that asbestos-cement bulk heads are vulnerable to carbonic acid attack in canals and estuaries. This is due to biological actions which produce excessive amounts of dissolved carbon dioxide, which decreases the water's pH to values of less than 7.

Building Insulation Asbestos Sources

Indoor asbestos air pollution concentrations are affected by the use of asbestos insulation and decorative materials containing asbestos. A study of 116 samples collected from 20 buildings in 5 cities found average chrysotile fiber concentrations from 2 to 200 nanograms per cubic meter. Overall ranges were from non-detectable levels to 800 nanograms per cubic meter (Nicholson et al. 1975). Buildings with fibrous asbestos sprays used as a fire proofing material on structural surfaces had significant asbestos contamination potentials. Indoor asbestos concentrations in these buildings were approximately 20 nanograms per cubic meter greater than the outside ambient conditions. Sawyer (1977) found large concentrations of asbestos fibers in libraries and other study areas of Yale University. A USEPA (1978) report cited other studies which found asbestos concentrations of up to 200 nanograms per cubic meter in schools using undisturbed asbestos insulation. This report also noted that the air quality conditions in homes of asbestos workers had chrysotile concentrations as high as 5000 nanograms per cubic meter. It is assumed that contamination of the workers' home is caused by fibers transported from work areas.

Nicholson et al. (1975) concluded that significant contamination can occur in building air supply systems where fiber-type asbestos fire proofing materials are used. Contamination of building air supplies can also be caused from the erosion of asbestos materials used for decorative acoustical purposes. However, no contamination was found in buildings where cement-type (non-fibrous) spray material was used. It was also found that optical microscopic analysis of building air was ineffective and that electron microscope procedures were necessary. McCrone (1980) states that the largest single source of asbestos in building air is from insulation since it has been used in most commercial and industrial buildings constructed in the past 50 years. On March 2, 1977, the EPA proposed amendments to the National Admissions Standard for asbestos which would restrict the spraying of all materials which contain more than 1 percent asbestos by weight (Sawyer and Spooner 1978).

Besides the contamination of building air by asbestos from fire proofing materials, the fall-out of fibrous asbestos from decorative and acoustical spray is also important. Sawyer and Spooner (1978) state that the asbestos fiber dispersal is continuous for long periods and at low rates. Contamination may occur without actual physical disruption of the fiber bearing material and may simply be caused by degradation of the adhesive material used for placement. Variations in the fall-out rates are due to structural vibration, humidity changes, air movement caused by heating and ventilation equipment, and air turbulence and vibrations caused by human activity. The rate also gradually increases because of aging of the adhesive material. Fall-out can result in concentrations ranging from zero for cement-type materials in good repair to 100 nanograms per cubic meter for deteriorating fiber-type applications. There have also been several cases where vandalism of asbestos material in school buildings resulted in substantial asbestos fall-out and contamination of building air.

Municipal Water Concentrations of Asbestos Fibers

Millette et al. (1979) summarized asbestos water concentrations for U.S. water supplies. Based on the analyses of 365 cities in 43 states (including Puerto Rico and the District of Columbia), it was found that the majority of U.S. water consumers are not exposed to asbestos concentrations greater than one million fibers per liter. In a few areas such as the San Francisco Bay Area and the Pacific Northwest, exposure to asbestos ranges from one to 100 million fibers per liter. Seventy-nine percent of all of the reported cities had concentrations less than one million fibers per liter. Ten percent of the cities had concentrations between one and 10 million fibers per liter. The remaining 11 percent had concentrations greater than 10 million fibers per liter. It was also found that the majority of consumers receiving water from asbestos-cement pipe distribution systems were not significantly exposed to asbestos fibers. However, water consumers could be exposed to asbestos fibers intermittently if asbestos-cement pipe tapping work was done improperly. In addition, in areas with very aggressive water, consumers with asbestos-cement water pipes may be exposed to concentrations greater than 10 million fibers per liter.

Users of water from cisterns collected from roofs having asbestos tiling material can be exposed to high concentrations of asbestos fibers. Water collected from typical asphalt asbestos shingle roof surfaces are low in asbestos.

Major water utilities using Lake Superior as a source have recently installed filtration plants so that their finished water contains asbestos below significant fiber concentrations. Some areas using unfiltered water from reservoirs may be exposed to high concentrations of fibers incorporated into organic matter. Except for the Duluth, Minnesota situation, there have not been any documented cases of direct contamination of drinking water supplies by industrial asbestos effluent. The Great Lakes Research Advisory Board (1975) stated that up to 87 million fibers per liter had been reported for Duluth area drinking water. Beaver Bay drinking water supply contained as much as 250 million amphibole fibers per liter. Concentrations in Duluth corresponded to about 0.2 milligrams of asbestos per liter with fluctuations caused by seasonal changes in lake circulation. Cook et al. (1975) conservatively estimates fiber counts for the 1973 Duluth water supply at one to 30 million amphibole asbestos fibers per liter with a mass concentration of one to 30 micrograms of asbestos per liter.

The USEPA (1978) reports that Canadian water supplies contain one to 170 million fibers per liter. The fiber concentrations in 22 water distribution systems in Ontario reported by the USHEW (undated) showed an observed range of 0.14 to 40 million fibers per liter. The average was approximately 20 million fibers per meter. Wigle (1977) presented data from the water supplies of 4 cities in Quebec known to have high asbestos in the area. Raw water samples had concentrations ranging from 13 to more than one thousand million fibers per liter. Filtered water samples ranged from one to two hundred million fibers per liter.

Millette et al. (1979) listed data from many municipal water supplies in the U.S., including several near Castro Valley. Table 8-15 summarizes these reported asbestos fiber concentrations from municipal water systems near Castro Valley. Most of the observed concentrations were low, although two reported greater than one million fibers per liter. One sample for San Leandro had 2 million fibers per liter, while one from Hayward had 34 million fibers per liter. The other samples from Hayward were much less. The average chrysotile asbestos concentration in these local water supplies were approximately one million fibers per liter. The amphibole asbestos fiber concentrations averaged approximately 100 thousand fibers per liter. Samples collected from the San Francisco water supply, however, contained more chrysotile asbestos fibers per liter than any other location in the country. One sample collected at Crystal Springs reservoir contained 130 million fibers per liter. Two other Bay Area reservoirs had raw concentrations greater than 100 million fibers per liter. Sixteen finished Bay Area water supply systems had chrysotile asbestos concentrations over 10 million fibers per liter. Seventeen others had concentrations between one and 10 million fibers per liter. Although some asbestos pipe may be involved, the primary source of asbestos in San Francisco water is the erosion of serpentine rock formations, including reservoir linings. Water supplies for the Bay Area have been affected by serpentine mineral formations for many years. It is possible that long-term residents of the San Francisco Bay Area have been exposed to large concentrations of chrysotile asbestos fibers in their drinking water for over 40 years. Fiber concentrations from the different water systems vary and fluctuate with different hydrologic conditions. Current San Francisco water treatment practices include filtration, plus blending of the local waters exposed to the serpentine with water from the Hetch Hetchy reservoir in the Sierra Foothills. Water from the Hetch Hetchy reservoir does not contain any detectable asbestos.

TABLE 8-15. REPORTED ASBESTOS CONCENTRATIONS IN VARIOUS WATER SUPPLY SYSTEMS NEAR CASTRO VALLEY

Location	Number of Samples	Amphibole Asbestos concentrations (x10^6 fibers/l) min.	max.	ave.	Chrysotile Asbestos concentrations (x10^6 fibers/l) min.	max.	ave.
Alameda	1	--	--	0.1	--	--	0.6
Alameda County	4	0.03	0.05	0.04	0.04	0.3	0.2
Albany	3	0.02	0.1	0.07	0.02	0.4	0.2
Castro Valley	1	--	--	0.1	--	--	0.8
Chabot	1	--	--	0.03	--	--	0.3
Fremont	4	0.03	0.3	0.1	0.03	0.3	0.2
Hayward	7	0.05	1	0.4	0.05	34	6
Livermore	1	--	--	0.05	--	--	0.03
Newark	1	--	--	0.03	--	--	0.5
Oakland	16	0.02	0.6	0.2	0.02	1	0.3
San Leandro	8	0.01	0.2	0.05	0.01	2	0.3
Total	47	0.01	1	0.1	0.01	34	0.9

Source: Millette, et al 1979.

The potential for release of fibers from asbestos pipe in closed loop water systems has been studied in many parts of the country (Millette et al. 1979, Hallenbeck et al. 1977, Hallenbeck 1977, Kirmeyer 1979 and Harrington et al. 1978). In certain cases, several hundred million fibers per liter of chrysotile asbestos were observed in drinking water. However, most of the samples studied had concentrations of one million fibers or less. In areas with aggressive water, however, consumers have been exposed to asbestos concentrations ranging from one million to 100 million fibers per liter (depending upon pipe length and water flow). Another problem with asbestos-cement pipes occurs when the pipe is tapped. Tapping involves cutting a hole into the pipe to add an additional service connection. Some tapping devices allow the cutting debris to enter the pipe where it can cause high asbestos concentrations in the distribution system for many weeks. Tapping devices are available which flush the debris from the hole and minimize contamination.

Millette et al. (1979) states that samples collected from dead-end areas and incompletely flushed fire hydrants can have high asbestos fiber concentrations because of accumulation of sediment from previous pipe tappings. This occurred in Amherst, Massachusetts, where a sample taken from a dead-end branch system contained almost 200 million fibers per liter. In contrast, water from the cross-linked portion of the distribution system contained essentially no fibers. A sample of the pipe showed no signs of deterioration.

Miscellaneous Household Asbestos Sources

As noted previously, there are about three thousand commercially available products that contain asbestos. However, the U.S. Department of Health, Education, and Welfare (HEW) (1978) states that although a product may contain asbestos, it does not necessarily pose a health risk. Some products contain asbestos incorporated in paint or plastic resins. The asbestos fibers from these products cannot become airborne unless they are badly worn, damaged or sanded. Identification of products containing asbestos is difficult since ingredients are not usually listed by manufacturers. HEW lists common household products containing asbestos. These include heat-resistant mats, barbeque mits, heavy-duty flame proof clothing, vinyl flooring (excluding linoleum), home and furnace insulation, asbestos-cement wall panels, and ironing board covers. The Consumer Product Safety Commission investigated asbestos-cement panels in Puerto Rico. They have banned patching compounds containing inhalable asbestos and artificial fire place ashes containing asbestos. They have also required certain manufacturers to recall hand-held dryers because of asbestos insulation in the handles.

Rohl et al. (1975) analyzed spackling, patching and jointing compounds sold in New York City retail stores. They found that many of these materials contained asbestos as well as other biologically active substances. Measurements suggested that home repair work (such as mixing and sanding) involving the use of these materials may result in exposure to dust concentrations sufficient to produce diseases. The Consumer Product Safety Commission (USHEW 1978) banned wall patching compounds sold in dry forms which are mixed with water or are in ready-mixed pastes. Before the ban, half of the patching compounds on the market contained asbestos and were without ingredient labels.

Asbestos fibers in these products are released into the air when the dried patching compound is sanded or scraped during finishing and cleanup. These materials were banned in January of 1978. The Consumer Product Safety Commission also banned artificial fire place ashes (marketed as "emberizing" material) that were commonly attached to gas fired artificial logs or scattered loose in artificial fireplaces.

Other common household items and foods may also contain detectable asbestos fibers. Cunningham and Pontefract (1973) detected asbestos fibers in beer, wines, soft drinks, and city drinking water at levels generally ranging from one to 11 million fibers per liter.

Controversy surrounds talc as a potential source of asbestos contamination. Suta and Levin (1979) summarized various studies of asbestiform minerals which may constitute major fractions of commercial talc. Other studies reported analyses of consumer talcum powders containing up to 14 percent asbestos of various forms. Talc is used in many different ways, including as a carrier for the application of pesticides. It is also used as a free-flow agent, anti-caking agent, form release agent, polishing agent, and as a dispersant or filler during the preparation of processed foods and additives. It has also been used as a lubricant in dried spices and flavoring mixes, and as a vehicle and dispersant agent for a variety of foods. Some of the foods talc is used in include: ground nuts (as a polishing agent); chewing gums and candies (as a mold release agent); and salami (as an anti-caking agent). Talc impregnated paper has also been used to package foods such as meat, salt, macaroni, rice, corn flakes, and dry milk. Talc has been extensively used in processing rice as an abrasive and polishing agent. One third of the rice consumed in the U.S. is non-enriched, talc and glucose coated rice.

McCrone (1980) disagrees with the concentration of asbestos fibers in talc. In a study of one hundred samples of talc from commercial U.S. mines, chrysotile asbestos was found in only one sample. However, this conclusion was based on dispersion staining and polarized light microscopy, supplemented by X-ray distraction. It is possible that electron microscope procedures would detect asbestos fibers in the talc.

Asphalt or vinyl asbestos floor tile was reported to contain 15 to 25 percent asbestos (Murphy et al. 1971). The fibers in floor tiles are firmly imbedded in the binding material and is therefore not a common source of asbestos fibers. However, there have been reports of floor tile installers who have had asbestos-related disease problems (they had frequently sanded asphalt and vinyl tile floors prior to installation). Air concentrations of asbestos fibers during floor sanding operations can be as much as 1000 fibers per milliliter.

Studies have also shown that homes of asbestos workers can also become highly contaminated with asbestos fibers (Anderson et al. 1974). Dusts are brought home by the workers on their bodies and clothing where the fibers can remain for long periods. Samples of settled dust on the rafters of workers' homes were found to contain asbestos fibers from the workers' factory. Environmental contamination from occupational sources may be more widespread than previously suspected, indicating the need for more stringent hygiene for asbestos workers.

Miscellaneous Asbestos Sources

Rohl et al. (1977) reports very high asbestos fiber air concentrations in the vicinity of roads surfaced by quarried serpentine crushed rock in the Rockville, Maryland area. This crushed serpentine has been extensively used for paving roads and other surfaces, and includes chrysotile and tremolite asbestos. Air concentrations of asbestos near these roads are about one thousand times greater than those typically found in urban ambient airs of the United States. Ten to fifty fibers per liter (two to five thousand nanograms per liter) have been observed. The sampling locations were widespread throughout the area and included school parking lots, side roads, and heavier roads carrying light to moderate traffic. The fiber counts of 10 to 50 per liter were obtained by optical microscopy procedures and only included fibers greater than five microns in length. Electron microscopy procedures would have enabled mass concentrations to be calculated directly.

Runoff from roofs covered with asbestos tile material in St. Croix, Virgin Islands, had asbestos concentrations of 500 million fibers per liter. Several buildings in the Virgin Islands, and others on St. Thomas Island, used roof drainage systems for water supplies (Millette et al. 1979). Rain water collected from a "life time" asbestos roof on a house in Kentucky showed concentrations of 400 million fibers per liter of chrysotile asbestos. When these values are compared to the rain water asbestos concentrations mentioned previously, they are found to be much higher than suburban rain conditions. Comparison of cistern roof systems constructed of asbestos asphalt shingles in Kentucky (30 years old) and in Ohio (2 years old) found no detectable asbestos fibers in the runoff. Apparently, the asphalt bonds the fibers well enough to prevent significant numbers from contaminating the water supply (Millette et al. 1979).

In this Castro Valley study, roof top particle samples contained appreciable concentrations of asbestos fibers. Fibers were found mostly on asphalt shingled roofs with concentrations of two billion fibers per gram of debris (total solids). Particulate material collected from wooden shingled and shaked roofs in the Castro Valley area had concentrations of asbestos fibers of 300 million fibers per gram of debris. The commercial composite sample included a mixture of roof types such as gravel, tar, wood, and asphalt. Fiber counts were approximately seven million fibers per gram of debris. It is not known if the asbestos fibers on these roofs are associated with atmospheric dry fallout, precipitation, or weathering of the roof material. Because the asphalt roofs had much greater concentrations, it can be expected that the erosion of the asphalt roofing materials and patching compounds are responsible for most of the observed asbestos fibers. The observed asbestos fibers were very small and were about one micron in length and less than one tenth of a micron in diameter. This implies that they were fibrils and not gross bundles of asbestos fibers embedded in larger particulates.

ENVIRONMENTAL EFFECTS OF ASBESTOS

Inhalation Effects and Air Quality Standards

The only asbestos air quality standards currently enforced in the United States are for occupational exposures. However, National Research Council Studies (1971) indicate that a much larger portion of the general population has inhaled and retained asbestos fibers than had formerly been realized. In fact, most urban dwellers have some fibers in their lungs. Bruckman and Rubino (1975) summarized various studies where asbestos related diseases were found in populations with no history of occupational exposure to asbestos. They state that urban dwellers have large quantities of asbestos fibers in their lungs. They point out that the smaller asbestos fibers (less than five microns in length) are incapable of producing lung cancer. However, it has not been demonstrated that the short asbestos fibers are incapable of inducing mesothelioma. Plumlee (1975) states that the exposure data available from occupational studies (by current analytical methods) are too unreliable to extrapolate ambient air quality standards. He feels that it is more justifiable to control, to the maximum practical extent, the major sources of asbestos entering the environment.

The USEPA (1978) states that a significant fraction of inhaled asbestos fibers are coughed up from the respiratory track and swallowed, leading to an ingestion exposure from air sources. Exposures of up to 0.1 microgram per day can occur. However, the average population exposure is from 0.02 to 0.05 microgram per day. These estimates are based upon the assumption that half of the asbestos inhaled will be swallowed with typical ambient levels of one to ten nanograms of chrysotile asbestos per cubic meter of air. Water ingestion can total about two hundredths of a microgram of asbestos per day. It is felt that inhalation can cause exposures equal to that of direct ingestion.

Bruckman and Rubino (1975) recommend an ambient air quality criteria for asbestos of 30 nanograms per cubic meter which they estimate would result in 150 nationwide fatalities a year. Almost all non-urban areas have asbestos levels typically less than one nanogram per cubic meter. Urban areas usually have ambient air concentrations below the 30 nanograms per cubic meter proposed standard. Bruckman and Rubino also propose a maximum allowable asbestos mass emission standard for manufacturing sources of 24 grams of asbestos fibers per day. This is based upon dispersion calculations resulting in a maximum ground-level exposure of 30 nanograms per cubic meter. They also recommend a maximum allowable average asbestos plume concentration of 25 micrograms per cubic meter. Plumlee (1975) found many weaknesses in Bruckman and Rubino's presentation and stated that their standards were not stringent enough. He states that asbestos emissions should be less than the standards that they proposed. Although Bruckman and Rubino's standards may not be adequate, it does seem reasonable to believe that they should not be exceeded.

Occupational standards to protect workers from excessive asbestos exposures have been in use for many years. In 1978 the National Institute for Occupational Safety and Health (OSHA) proposed an eight hour exposure criteria of 100 fibers per liter and a peak exposure of 500 fibers per liter.

This standard has been made more stringent by a factor of 50 since the pre-1975 standard. The fibers considered in the occupational standards are in the size range of five to 100 microns in length. Optical microscopic procedures are therefore adequate in determining compliance with OSHA standards.

Health Hazards of Asbestos Ingestion and Water Quality Criteria

Hallenbeck (1977) states that workers exposed to high levels of airborne asbestos have a greater risk of contracting cancer of the digestive system. This is thought to be related to swallowing asbestos that was inhaled. The incident of gastrointestinal cancer in asbestos workers is two to three times the background level of the general population (Kirmeyer 1979). The dose-response relationship between occupational exposure to asbestos and the risk of gastrointestinal cancer is very poorly defined. There is also evidence suggesting that asbestos fibers may penetrate digestive system tissue (Hallenbeck 1977, Cunningham and Pontefract 1974). However, other studies of animal exposure to asbestos were inconclusive because the duration of the studies were shorter than the animal's life span. Recognition of the lag in the dose-response relationship to exposure of asbestos is reflected in the court opinion on the Reserve Mining Company case in Minnesota. The Great Lakes Research Advisory Board (1975) summarized the courts opinion by stating that occupational exposures require a lag time of 20 years or more between initial exposure and the onset of cancer.

It seems that it is the physical properties (fibrous) of asbestos (instead of its chemical composition or trace elements) which determine its carcinogenity (Kirmeyer 1979). Harrington et al. (1978) states that asbestos fibers in tap water can be shorter than those observed in occupational environments. Recent evidence suggests that fibers between 0.25 and 1.25 microns in diameter and 10 to 60 microns in length may be the most important cancer causing agents. These are relatively large fiber sizes and they are not common in water supplies. However, Langer et al. (1978) states that controversy has arisen concerning the biological activity of small fibers. Experimental evidence exists which shows that short fibers can be active cancer causing agents. Other data suggest that short fibers are not cancer causing. These different studies were conducted in both animal and "in vitro" test systems. Williams et al. (1979) tested the toxicity of different asbestos forms on embryonic human intestine and adult rat liver cells. They found that chrysotile asbestos was more toxic than amosite and crocidolite asbestos. Amosite and crocidolite asbestos were about equivalent in toxicity.

Kirmeyer (1979) states that there have been at least four epidemiological studies to determine if ingestion of asbestos fibers poses a possible health hazard. Three of these studies (Duluth, Minnesota; Quebec, Canada; and Connecticut) indicated no relationship between fiber count and cancer incidents. The fourth study, conducted in the San Francisco Bay Area, suggested a possible link between asbestos ingestion and cancer incidents. The USEPA, however, concluded that the results from the San Francisco study are not definitive enough to justify extensive modifications to the water supply treatment and distribution system. They are conducting additional studies to determine whether there is a need for changes in water treatment. Another study is also being conducted in the Puget Sound area by the Fred Hutchinson

Cancer Research Center. This study will compare cancer rates of persons ingesting various quantities of asbestos from drinking waters in Everett, Seattle, and Tacoma. An area on the Kitsap peninsula where industrial exposure to asbestos is known to occur will also be included.

National Academy of Sciences research indicates that no acute health hazards exist from ingesting asbestos fibers in drinking water supplies at current concentrations. However, they do suggest minimizing exposure through proper water treatment (Kirmeyer 1979). The EPA has not set standards for asbestos in drinking water, but they do suggest that asbestos concentrations be kept below 300 thousand fibers per liter for all fiber sizes in order to keep cancer risks below 10^{-5} (USEPA 1978). The EPA also states that water concentrations of asbestos are usually less than a million fibers per liter for all sizes. However, significantly high values of up to 100 million fibers per liter have been found where water systems have been in contact with asbestiform minerals or where contamination of the water supply exists. They estimate that direct water ingestion leads to exposures of less than 20 nanograms per day.

The EPA's criteria for asbestos in drinking water (USEPA 1978) recommends that asbestos concentrations be limited to 0 fibers per liter under ambient water conditions to ensure maximum protection of human health. A risk level of 10^{-5} (one death per 100,000 people) corresponds to a criteria of 300,000 fibers per liter. A risk level of 10^{-6} and 10^{-7} corresponds to fiber concentrations of 30,000 and 3,000 asbestos fibers per liter, respectively. The American Water Works Association's goal of 0.1 turbidity units in a water supply will keep asbestos levels at reasonably low levels (Kirmeyer 1979). Kirmeyer also states that turbidity spikes in filtered waters of less than 0.35 turbidity units have caused increases in asbestos counts from non-significant levels to 12 million fibers per liter.

Effects of Asbestos on Aquatic Life

Very little data exists measuring the contamination of aquatic life from asbestos. It is expected that high asbestos fiber concentrations interfere with oxygen transfer through gill structures of fish because of actual physical blockage by the fibers. However, these concentrations would have to be extremely high. Other suspended solids material would result in similar effects. Many tests examining the health effects of asbestos have been conducted on various species of animals and have shown severe detrimental effects due to high asbestos exposure. However, there have not been any studies conducted specifically concerning the effects of asbestos on aquatic life. The USEPA (1978) has not established criteria for asbestos concentrations in waters for fresh or marine aquatic life. They state that there is insufficient data to establish such criteria.

The Fate of Asbestos Fibers in the Environment

Suta and Levine (1979) state that very little is known about the ultimate fate of asbestos fibers once they are released to the environment. It is known that fibers can be readily subdivided by mechanical means into fibrils of sub-micron diameter. It has not been established if the sub-division occurs by natural processes. Natural forces such as erosion, grinding, abrasion, and moisture and temperature gradients may be responsible for their eventual sub-division. Suta and Levine also report that all types of asbestos resist prolonged attack by highly basic materials (i.e., materials with pH values much greater than seven). However, the hydroxol group in chrysotile will react with weak acids (including water) causing the release of magnesium and silica. Even though there is some degradation, it is believed that the fibers' general morphology is retained.

Temperatures required for thermal decomposition of asbestos are seldom attained in the natural environment. Dehydration of chrysotile occurs at about 100°C followed by dehydroxylation at temperatures as low as 200°C. At 800°C full dehydroxylation is achieved resulting in an amorphous residue. The thermal decomposition of amphibole asbestos occurs at similar temperatures (Suta and Levine 1979).

Before 1950, asbestos fibers were regarded as being thermally resistant and fire proof (Hodgson 1979). No precise limitations were known about the degree of heat resistance of asbestos fibers. The insulating properties of asbestos, however, are not thought to be reduced by thermal degredation since its insulating properties depend on its fibrous nature and not on the thermal conductivity of individual fibers.

Morgan and Cralley (1973) report that the stability of chrysotile fibers in mineral acids has been studied extensively. Acids attack chrysotile by reacting with the hydroxyl groups on the surface of the fibrils. At room temperature, the rate of reaction is directly proportional to acid concentration. Clark and Holt (1961) state that chrysotile fibers degrade more readily with alternating acidic and basic conditions, than under either condition alone. Although chrysotile does dissolve slowly in water, it does so at a rate 100 times less than in 0.1 normal hydrochloric acid. Morgan and Cralley (1973) also state that the amphiboles are much more resistant to acid attack than chrysotile.

Williams et al. (1979) reports that leaching the three major forms of asbestos in sterile deionized water for three days did not appreciably affect their toxicity. Leaching in hydrochloric acid, however, slightly increased the toxicity of amosite and crocidolite, and greatly decreased the toxicity of chrysotile. During leaching, the deionized water was found to contain substantial levels of magnesium and calcium ions (released from the asbestos fibers). Much larger levels of these ions were released during leaching with hydrochloric acid.

The thermal degradation and stability of asbestos fibers is not likely to be important under normal environmental conditions. However, the stability of the materials used to bind asbestos fibers in products (especially asbestos cement) is extremely important. As mentioned previously, waters containing high levels of dissolved carbon dioxide (carbonic acid), alkalinity, calcium, or hydrogen sulfides can degrade the binder and release large quantities of asbestos fibers into the water.

The Movement of Asbestos Fibers in Soil, Water and Air

Once asbestos fibers are released into the environment, they are carried away by the water and air currents or mixed with soil at landfill sites. Transport of asbestos in the environment occurs by interactions with wind and water on waste piles and soils containing asbestos fibers. Scavenging effects of rain waters on atmospheric asbestos increases concentrations in runoff. Waterborne asbestos fibers may be removed by water treatment processes. Contaminated sludge generated by treatment processes can either be incinerated (which discharges asbestos back into the air) or disposed of in landfills (which can then contaminate local soils). Of the three transport media in the environment, soil retention appears to be the most effective as long as good cover material is provided. Air movement of fibers can carry asbestos many miles away from its original disposal site. Water currents can also carry asbestos many miles away from disposal sites.

Fuller (1977) studied the migration of asbestos fibers in soil. He found that soils filter out asbestos readily on or near the soil surface. During soil formation, the rate of movement of clay sized asbestos particles (less than 2 microns in diameter) is about one to ten centimeters per 3,000 to 40,000 years. As noted previously, asbestos weathers slowly in the natural environment and the weathered by-products would be no more deleterious to groundwater quality than natural silicates from soils or clays. He concludes that asbestos particles less than two microns in size are slowly mobile and are sorbed onto the surface layers of soils and clays. Asbestos particles greater than two microns, however, are immobile and are retained completely on the surfaces of the soils. The small asbestos particles are reported to penetrate the soil pores but not to a significant depth. Under dry conditions, asbestos can be transferred to the air by wind turbulence, unless it is incorporated into the soil horizon. Fuller states that, although there is no data on the mobility of asbestos in soil, predictions about its behavior can be made with reasonable confidence. Since the weathering products of asbestos are the common non-hazardous salts of calcium, magnesium, and silica, physical transport is the only mode of asbestos transport in soil which is of environmental significance. Except as a possible dust hazard, he states that asbestos does not offer a serious contamination risk to soil or groundwater supplies and thus, cannot be classed as a soil pollutant. Plowing or tilling asbestos into the soil where it can be mixed and greatly diluted reduces the likelihood of transfer to the air. Surface waters, as noted before, can be polluted by erosion products. Consequently, both air and water erosion should be minimized at asbestos disposal sites.

The ability of a receiving water body to transport asbestos fibers depends upon the current and depth of the water and the settling characteristics of the asbestos fibers. For the asbestos fibers observed in the Castro Valley study, settling velocities in water are approximately 10^{-7} to 10^{-6} centimeter per second. Larger asbestos fiber bundles of several microns in diameter would have settling velocities of approximately 10^{-3} centimeter per second (Stern 1968). As an example, a fiber 0.1 micron in diameter with a settling velocity of 10^{-6} centimeter per second would require approximately one month to settle one foot in a quiescent water column. Asbestos fibers in water can therefore be generally considered nonsettlable suspended particles. Very large fiber bundles, however, can settle out as much as one hundred times faster than the above example and would be capable of reaching lake sediments if discharged into a motionless body of water. However, the smaller fibrils would most likely remain suspended. Durham and Pang (1975) traced asbestos fiber movement from the mining and milling operations at Silver Bay to the Duluth area of Lake Superior. They found a steady counter-clockwise flow around Lake Superior which tended to move the asbestos fibers from Silver Bay towards Duluth (a distance of about 50 miles). The fibers then moved eastward along the south shore. These currents averaged only a few centimeters per second so that the fibers either gradually settled out or diffused into the main body of the lake. Therefore, the mining operation had little effect on Lake Superior water quality at the eastern end of the lake.

The National Resource Council (1971) states that precise information is not available on the atmospheric dispersion or ultimate fate of asbestos emitted into ambient air. Plumlee (1975) states that preliminary data concerning the asbestos content in the Greenland ice cap shows that asbestos concentrations increased in recent times. The National Research Council (1971) and Selikoff (1972) found that asbestos fibers in air diminished rapidly beyond one kilometer from an anthophyllite quarry but were still detectable at distances of 25 and 50 kilometers. Suta and Levine (1979) made a simple calculation of drift distances for two sizes of asbestos fibers. If the fibers were injected into the air at 50 feet with a 10 mile an hour cross wind, a small fiber with a diameter of 0.1 micron and a length of 100 microns would drift for more than 1000 kilometers. A large fiber one micron in diameter and 50 microns long would drift for more than 10 kilometers.

The settling of an asbestos fiber once released into the air is determined by its mass, shape, and axis directions (Sawyer and Spooner 1978). The distribution of these characteristics among fibers is quite large so settling characteristics for the different asbestos fibers will vary greatly. The settling velocity is most dependent upon fiber diameter and much less upon fiber length. For fibers similar to those found on the streets of the Castro Valley watershed (about one micron in length and less than 0.10 micron in diameter), the gravitational settling velocity in air would be between 0.0001 and 0.0005 centimeter per second. As a comparison, fibers that are likely to be dispersed from overhead insulation in buildings (one to five microns in length and one micron in diameter) would have settling velocities in air between 0.01 and 0.001 centimeter per second. The time for these insulation fibers to settle from a nine foot ceiling in still air would vary from 8 to 80 hours. Turbulence would prolong the settling and also cause reintrainment of the fibers. Sawyer and Spooner (1978) state that during the time that the fibers remain airborne, they can move with the air currents and contaminate areas distant from the point of release. This is especially important when considering the atmospheric dispersion of asbestos fibers. As noted previously, fibers can be transported for many miles downwind from the discharge location. In addition, the impaction of fibers with the ground at a distant location does not mean that the fibers would remain permanently at that location. Asbestos fibers are quite easily reintrained into the wind due to different types of atmospheric or man-made turbulence.

Water Treatment to Remove Asbestos Fibers from Drinking Water Supplies

As part of the discussion on the ultimate fate of asbestos fibers, it was noted that there is great potential for asbestos fibers to be transferred from one transporting media (soil, water or air) to another. One of these potential media transfer mechanisms is water treatment of municipal water supplies. The fundamental idea of water treatment is to remove pollutants from a water supply and safely dispose of the separated pollutants in the soil (at landfills) or by incineration. However, if the sludge generated by water treatment is incinerated, most of the asbestos fibers will be discharged into the air. The most appropriate sludge disposal practice available at this time is landfilling with minimum disturbance of the sludge and the application of an appropriate cover material. The sludge should also be handled and disposed of in a wet slurry form, if possible, to minimize fugitive dust losses of asbestos fibers back into the air. It has been well established that fairly simple water treatment processes such as filtration preceded by chemical pre-treatment removes significant amounts of asbestos, thus improving domestic water quality. Millette et al. (1979) states that the filtration plants currently used in Duluth maintain asbestos fiber concentrations below 100 thousand fibers per liter. The Duluth treatment systems are mainly removing amphibole fibers. The removal of chrysotile fibers is much more difficult to achieve (Kirmeyer 1979). He reports that if the turbidity of the finished water was less than 0.1 turbidity units, the chrysotile fiber concentrations were reduced from about seven million fibers per liter in the raw water to less than 20 thousand fibers per liter in the finished water (50 percent of the time).

The Great Lakes Research Advisory Board (1975) has studied treatment techniques for the removal of asbestos fibers such as simple sand filtration, diatomaceous earth filtration, chemical coagulation, or combinations of these procedures. The most effective method used chemical coagulation with iron salts and polyelectrolytes followed by filtration. This technique resulted in more than 99.8 percent fiber removal from water that initially contained 12 million fibers per liter. Ordinary sand filtration was reported to remove about 90 percent of the individual asbestos fibers from the water supplies.

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